SPATIAL VALUATION OF ECOSYSTEM SERVICES IN AGRICULTURAL LANDS

A Dissertation

by

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ABSTRACT

Agricultural lands provide various provisioning ecosystem services to humans, including food, water, fibers, fuel, and components of pharmaceuticals. These ecosystems also support and regulate such services as pollination, water provision, and the retention of nutrients and soil. The value of these ecosystem services, while tremendous, historically has been vaguely defined and underappreciated.

This research built a comprehensive framework to spatially map and quantify the ecosystem services provided by agricultural lands in Galveston County, Texas using an open-source ecosystem services modeling tool called the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) models. Five ecosystem services models were investigated, including: water yield, nutrient retention, sediment retention, pollination abundance, and habitat quality. Biophysical data, such as land use/land cover, precipitation, evapotranspiration, soil and pollinator characteristics, and threats to habitat were input into the InVEST models to determine the amounts and spatial patterns of these ecosystem services. Results showed spatially distributed ecosystem services throughout the study area, with hot spots of ecosystem services where certain activities were concentrated, such as streams, croplands, and intensely developed lands. A hedonic price model was designed to appraise the value of these ecosystem services based on the prices of the agricultural land as well as other relevant factors (neighborhood, structure, and market segmentation). The model was used to estimate the marginal implicit price of a per unit increase in each ecosystem services variable.

The estimates suggested that ecosystem services were included in appraisals of the land prices – to various degrees of statistically significant correlation – except with regards to pollination abundance and habitat quality. The habitat degradation value, a derivative of the habitat quality model, was shown to be most closely correlated with land prices, which could be explained by highly degraded lands as a result of extensive cropping systems.

Together, this suggests that more planning, thoughtful policy making, and resource management could help avoid land degradation and prolonged effects that could potentially deplete more resources and habitats within (and beyond) these areas. Further model calibrations that include comparisons of different scenarios (e.g. a baseline scenario, constrained development, and non-constrained development) to manage these lands would help determine efficient steps forward, as accounting for the economic value of ecosystem services is now vital for managing and sustaining our irreplaceable natural resources.

DEDICATION

To my family, who has always believed in me.

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NOMENCLATURE

AIC	Akaike Information Criterion
ARIES	Artificial Intelligence for Ecosystem Services
AWS	Available Water Storage
CPI	Crop Productivity Index
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
ES	Ecosystem Services
FAO	Food and Agriculture Organization of the United Nations
GCAD	Galveston Central Appraisal District
GIS	Geographic Information System
GMM	Generalized Method of Moments
gSSURGO	Gridded Soil Survey Geographic Database
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
ISD	Independent School District
LULC	Land Use/Land Cover
MA	Millennium Ecosystem Assessment
NRC	National Research Council
NOAA	National Oceanic and Atmospheric Administration
PAWC	Plant Available Water Capacity
PES	Payments for Ecosystem Services

SE	Standard Error
SC	Schwarz Criterion
SSURGO	Soil Survey Geographic Database
UNCED	United Nations Conference on Environment and Development
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WCED	World Commission on Environment and Development

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CHAPTER I

INTRODUCTION

We are a part of numerous ecosystems, and those ecosystems are a part of us. An ecosystem is a dynamic combination of plant, animal, and microorganism communities and a nonliving environment interacting together as a functional unit (Millennium Ecosystem Assessment [MA], 2003). The environment and various ecosystems are considered natural capital, a form of a capital asset that, along with physical, human, social, and intellectual capital, is one of society's most important resources (National Research Council [NRC], 2005). It is, therefore, imperative to determine the value of these ecosystems in monetary terms, in order to balance them with other societally-recognized economic goods and services. Without such a value, there is no common reference for stakeholders and decision makers, and ecosystems become at risk of being treated as valueless (Costanza et al., 1997). This is because decisions are based largely on the associated benefits that can be gained or lost. Hurdles can also arise along the path to defining goals, furthering management plans, calculating environmental impacts, and justifying budgets for environmental projects.

Various ecosystem valuation approaches have been introduced and studied. Some have tried to cover every aspect of an ecosystem and its associated values in a spaghetti-type approach (Fisher et al., 2009), while others have lacked a unified paradigm of valuation (Boyd and Banzhaf, 2007). What has been missing from these attempts is a structural framework that is consistent, practical, and applicable to different scenarios

(MA, 2005). In other words, there is a need to consolidate pertinent work and ideas and use it to develop a more tangible approach to ecosystem valuation.

Among the extensive research that has been conducted in the field of economic ecosystem valuation, most studies concentrate on the maximum value of services and benefits provided by an ecosystem at its present state; however, they lack any consideration of future needs. The bulk of the relevant efforts to date appear to have missed a very important aspect of valuation, the valuation of sustainability. After all, natural resources are limited and can be depleted. What is being used today affects availability for future generations. Thus, it is important to address sustainable development in this valuation study.

The initial groundwork for sustainable development, Our Common Future, a study conducted by the United Nations World Commission on Environment and Development (WCED), was introduced in 1987 (WCED, 1987). The publication, also known as the Brundtland Report, examined critical environmental and development problems, and proposed practical solutions and approaches to sustaining the world's resources for the future. It was a first attempt at addressing issues related to the environment and development as a single matter, and was the foundation of the 1992 Rio Declaration on Sustainable Development at the United Nations Conference on Environment and Development (UNCED), generally known as The Earth Summit. Among the 27 principles stipulated in the document, Principle 3 states that "the right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations." Such an agenda has been interpreted and accepted by every nation as a primary goal in the service of sustainable development. However, to date, no specific and cohesive approach has been constructed to address the link between the environment and development. Each issue tends to be considered separately, and is not well conceived in a systematic manner. To fully achieve this agenda, it is crucial to develop a link between these two perspectives and interpret the relationship in monetary terms.

In addition to the aforementioned reasons to conduct this research, a thorough review of previous and existing studies is crucial to the development of a valuation framework. This endeavor will allow for an appropriate procedural plan to emerge through the course of this study. Validation of this research will also be conducted to elaborate upon the results produced.

Goal and Objectives

The overall goal of this research is to conduct a valuation of ecosystem services in a particular geographic area. The specific objectives are as follows: 1) to spatially map the ecosystem services within a set of agricultural lands; 2) to develop a spatial valuation model that links ecosystem services to land appraisal values; and 3) to interpret the relationships between agricultural land values and ecosystem services. Below, Fig. 1 shows a diagram summarizing the research procedure.

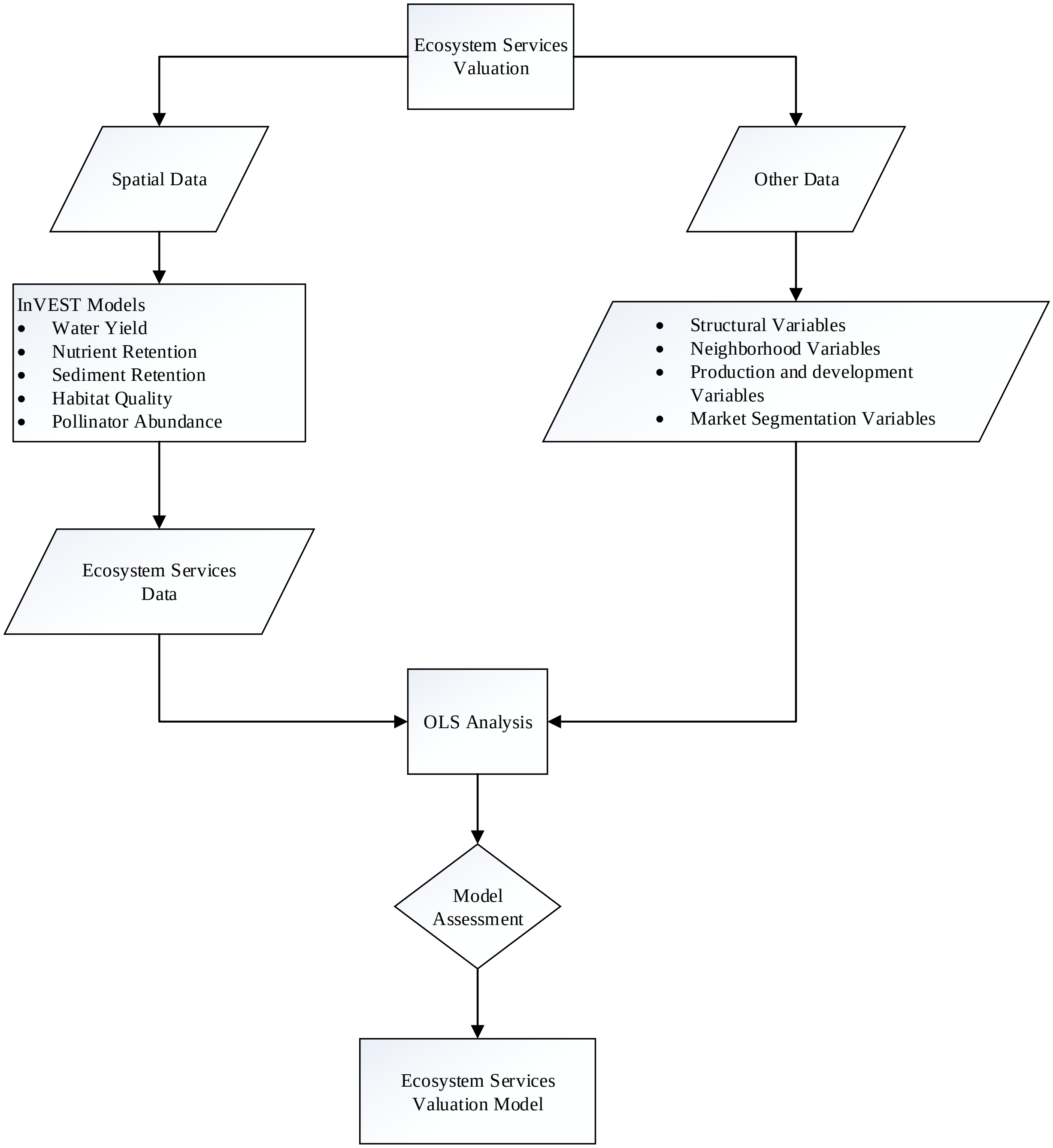

Fig. 1. Summary of research procedures.

Outline of the Dissertation

This study consists of six chapters. This chapter, Chapter I, introduces the research and its goals and objectives. Chapter II reviews previous studies relevant to this research. Chapter III covers data processing steps in InVEST that map and quantify ecosystem services within the study area. Chapter IV explains the research methodology (utilizing data from Chapter III) and the hedonic price model used as the framework for the valuation model. Chapter V reports the results obtained from InVEST and the hedonic model. Chapter VI concludes this research by discussing the results, suggesting further improvements that could be made, and specifying the limitations.

CHAPTER II

LITERATURE REVIEW

For this research, the relevant studies to date were reviewed, and two pillars, ecosystem valuation and land valuation, were examined. This chapter elaborates upon how they intertwine, and identifies the various opportunities for this research. Existing definitions and classifications related to ecosystem services helped this researcher choose the appropriate factors that would be most relevant to this project, and enabled the development of a valuation framework for this research.

Ecosystem Valuation

The need to develop a valuation of ecosystem services stems from the related need to economically assess the natural resources available in a given environment. Two common valuation methods include revealed and stated preference methods. *Revealed preference methods* infer preferences from observed market-based information. The values placed on environmental goods are assumed to be related to ecological services. Revealed preference methods include averting behavior models, hedonic pricing models, and recreational demand models. *Stated preference methods* make it possible to elicit preferences directly, through the use of a questionnaire. The value placed on environmental goods is investigated in hypothetical situations in which respondents reveal their preferences through valuation questions. Preferences and values are inferred from the collected responses. These methods include contingent valuations and choice modeling. Another approach, *benefit transfer*, relies on information obtained from existing studies that applied stated or revealed preference methods. Researchers employing this method do not collect any primary data (Boyle and Bergstrom, 1992; Desvousges et al., 1998). This method comes with certain limitations regarding the accuracy of the data and the non-systematic process used to conduct the analysis. Moreover, the benefit transfer approach uses empirical results from other geographical, ecological, and demographic areas and applies it to other scenarios and study areas. Therefore, difficulties in data applicability and inaccuracies in data transfer values can result.

Various ecosystem valuation ideas have been proposed in the relevant studies currently available (Costanza et al., 1997; Daily, 1997; Farber et al., 2002; NRC, 2005; MA, 2005; Boyd and Banzhaf, 2007). Most refer to ecosystem services as an indication of the environmental needs of an area of interest (i.e., services rendered by an ecosystem within a given area). Barbier et al. (2009) emphasized the importance of ecosystem services in meeting human needs, and how those needs determine the value of the associated ecosystem services. Many of the policies implemented by various federal, state, and local regulatory agencies can profoundly affect the nation's aquatic and related terrestrial ecosystems, and consequently, these agencies have an invested interest in better understanding the nature of such services, how governmental actions may affect them, and what value society places on them (NRC, 2005). Hidden social costs and benefits can potentially be revealed through the economic valuation of ecosystem services, and vital information that might otherwise remain unavailable to economic decision makers along different institutional scales can be collected (MA, 2005).

To properly perform valuations of ecosystem services, it is imperative to define what constitutes an ecosystem service. Several studies have attempted to define and classify ecosystem services (MA, 2003; De Groot et al., 2002; Boyd and Banzhaf, 2007; Wallace, 2007; Fisher and Turner, 2008). Despite these extensive works, the literature does little to distinguish exactly how ecosystem services should be defined (Boyd, 2007; Barbier, 2007; Fisher et al., 2009). Hence, there is still much work to do with regards to determining what, precisely, should be considered "ecosystem services."

One of the most comprehensive and widely regarded works is the Millennium Ecosystem Assessment (MA), a cooperative effort of several worldwide experts who assessed the effects of ecosystem changes on human wellbeing since 2001. The MA defines ecosystem services as benefits people obtain from their ecosystems. These include: 1) *provisioning services* such as food, water, timber, and fiber; 2) *regulating services* that affect climate, floods, disease, waste, and water quality; 3) *cultural services* that provide recreational, aesthetic, and spiritual benefits; and 4) *support services* such as soil formation, photosynthesis, and nutrient cycling (MA, 2005). This classification system is, understandably, not meant to fit all purposes. This has specifically been pointed out with regards to environmental accounting and landscape management valuations, for which alternative classifications have been proposed (Fisher et al., 2009). Boyd and Banzhaf (2007) presented a different definition, in which ecosystem services are not benefits humans obtain from their ecosystems, but rather ecological components directly consumed or enjoyed to produce human wellbeing. Fisher et al. (2009) largely drew upon the above definition, proposing that ecosystem services are those aspects of ecosystems specifically utilized (either actively or passively) to produce human wellbeing; functions or processes only become services if there are humans who benefit from them. Boyd and Banzhaf (2007) proposed a method of quantifying ecosystem services according to an environmental accounting system known as Green GDP, in which only final ecosystem services or end products are important from a welfare accounting perspective. Utilizing the terms intermediate services, final services, and benefits help to eliminate some of the ambiguity inherent in ecosystem services typologies, especially for economic valuation purposes (Fisher and Turner, 2008).

Land Valuation in the Context of Sustainable Development

The notion of sustainable development has been perceived by the public in various manners. One practical measure is to incorporate land price as a reference. One of the clarion calls of the MA was for increased and concerted research on measuring, modeling, and mapping ecosystem services, as well as on assessing changes in their delivery with respect to human welfare (MA, 2005; Carpenter et al., 2006; Sachs and Reid, 2006; Fisher et al., 2009). Land can be regarded as a differentiated product through a hedonic model, and an implication for welfare measurement (Palmquist, 1989). One way of estimating the indirect value of ecosystem services is via the prices people pay for the land that provides access to such services (Ma and Swinton, 2011). In fact, real estate is one of the few places in which environmental quality is traded on explicit markets

(Palmquist, 2005). Land prices inherently reflect the contributions made by the land and its surroundings, depending upon the type of land (such as agricultural, industrial, or residential). It is plausible to assume that the development needs of a particular locale are reflected in its real estate value, which also serves as a measurement of human welfare. Two types of land value widely regarded as typical references were determined to be worth considering for this research. First, land appraisal value is the basis for any real estate valuation of land parcels on the market. A parcel's real estate estimated value is appraised and determined by a specialist land appraiser. Second, by referencing the land appraisal value, a sales price is developed. This is the actual transaction price people agree upon to pay for the particular parcel of land.

Bridging Ecosystem Valuation and Development

Several studies have examined the influences of amenities on land prices (Polinsky and Shavell, 1976; Bartik, 1988; Cheshire and Sheppard, 1995; Tyrvainen and Miettinen, 2000). Surrounding characteristics have also been proposed as a determinant of land prices along the urban fringe (Hushak and Sadr, 1979; Chicoine, 1981). Leggett and Bockstael (2000) validated the significant effect of water quality on property values along the Chesapeake Bay. Geoghegan et al. (1997) developed a spatial model to explain the effects of surrounding land uses on residential values by including attributes such as percent of open space, diversity, and fragmentation of land use. Geoghegan (2002) found a significant effect of open space on residential land values in Howard County, Maryland. Kong et al. (2007) incorporated Geographic Information System (GIS) and landscape metrics to determine the positive amenity impact of proximate urban green spaces on house prices, and investigated the personal preferences of homeowners in Jinan City, China.

Among these various studies, few have deliberately assessed the relationship between environmental amenities and land prices. Ma and Swinton (2011) studied ecosystem services pertaining to agricultural land, and determined that ecosystem services – particularly those that support direct use – are likely to be capitalized in land prices. Bastian et al. (2002) validated the influence of environmental amenities including scenic view, elk habitat, and distance to town on agricultural land values through an analysis of GIS data.

While the effect of human development on land has been well measured in both monetary terms and other indicators, a useful way of assessing the monetary value of the environment and various ecosystems is still missing. Existing references, though they often address the significance of the environment on land prices, have not explicitly specified the monetary value of the ecosystem. Rather, they have examined only the relationship between ecosystem services and land prices. Hence, this research endeavors to fill in the gap and link monetary values to the environment and ecosystem services through land prices. Moreover, in this study the valuations of ecosystem services and development lands are conducted independently of one another. To date, there is no reference that cohesively links ecosystem services and development. It is, therefore, time to “connect the dots” so that sustainability can be pursued on both fronts.

This research proposes a spatial valuation framework that connects the environment and development through ecosystem services and land prices. The goal and objectives, theoretical framework, study area, and procedures of this research are described in the following sections.

Ecosystem Services and its Proxy Attributes

In order to construct a comprehensive framework for ecosystem valuation, the notion of ecosystem services need to be inspected. Even though there have been extensive research addressing ecosystem services, there can still be disagreements regarding what constitutes ecosystem services and whether ecosystem services should be considered. In order for the concept of ecosystem services to make a meaningful contribution to conservation research and general human welfare, it needs to be clearly defined and put into a framework that is operational for societal management decisions (Fisher and Turner, 2008). Classifying and packaging ecosystem services for meaningful and appropriate use requires a clear definition of what ecosystem services are, an understanding of the key characteristics and behaviors of these ecosystems and their services, and an understanding of the context in which the notion of ecosystem services will be used (Fisher et al., 2009). Therefore, a conclusive explanation is required to eliminate any ambiguity and provide a precise method of computation. These services indeed have no meaning if they cannot be described in a tangible fashion, such as in terms of monetary value.

Even with a clearly-defined notion of ecosystem services, it is almost impossible to develop a direct form of measurement. Such services are considered dynamic, and jointly produced by the various ecosystems present in specific land covers. Even if data on their productivity could be affordably collected, the levels of the different ecosystem services provided by the same land cover would likely be collinear (Ma and Swinton, 2011). To quantify ecosystem services, then, the heterogeneous attributes of the landscape are plausible determinants. Since ecosystem services are sustained by natural resources and the landscapes in and near the lands, the presence and area of, as well as the proximity to those resources and land covers can serve as proxy attributes for any unobserved ES (Ma and Swinton, 2011). By incorporating GIS into the analysis, spatial proxy attributes can be determined.

Agricultural land supplies and sustains ecosystem services that can provide benefits of various forms, such as food (crops, livestock, and fisheries), fiber (timber and cotton), fresh water, clean air, pollinator services, aesthetic and cultural values, etc. Only recently has agricultural land received the public's attention with programs such as payments for ecosystem services (PES). Such a program, run by a government or subsidized by a specific organization, agrees to provide incentives to farmers and landowners in exchange for more "green" farming (the management of lands in ways that can sustain and conserve natural resources). Table 1, partly adapted from Kroeger and Casey (2007), Boyd and Banzhaf (2007), and Ma and Swinton (2011), illustrates potential examples of ecosystem services for agricultural land and their proxy attributes.

Table 1
Key ecosystem services and their proxy attributes, adapted from Boyd and Banzhaf (2007) and Ma and Swinton (2011).

Benefits		**Implied Ecosystem Services**	**Example of Measurement Attributes**
Harvests			
	Avoided disposal cost	Pollinator populations	Wetlands, forests, grasslands, and conservation lands
		Soil quality	Soil quality
		Shade and shelter	Landscape metrics
	Avoided treatment cost	Water availability	Lakes, rivers, and wetlands
		Target fish	Fish populations and distributions
	Avoided pumping, transport cost	Crop populations	Croplands
		Target marine populations	Marine populations and distributions
	Birding	Biodiversity	Species richness index
Amenities and fulfillment			
	Angling	Natural land cover in viewsheds	Land covers
		Wilderness, biodiversity, varied natural land cover	Diversity of different land covers
	Swimming	Relevant species populations	Different species populations
Damage avoidance			
		Air quality	Air quality index
		Drinking water quality	Water quality index, total nutrient loadings
		Land uses or predator populations hostile to disease transmission	Threat assessment
		Wetlands Forests	Percentage of each land cover class in a parcel and surrounding areas

Table 1 (*continued*)

Benefits	Implied Ecosystem Services	Example of Measurement Attributes
Waste assimilation		
	Surface and groundwater	Water yield
	Open land	Percentage of water body
Drinking water provision	Aquifer	Ground water level measurement
	Surface water quality	Water quality assessment
	Aquifer availability	Water supply measurement
Recreation		
	Relevant species population	Species richness and distribution indices
	Surface water	Water availability
	Target population	Species richness and distribution indices
	Surface water	Water availability
	Beaches	Beach availability and accessibility

CHAPTER III

MAPPING AND QUANTIFICATION OF ECOSYSTEM SERVICES

Attempts to quantify ecosystem services have regularly been a focus of ecosystem services research. Several tools and models have been developed to facilitate accurate measurement. Most of these tools and models tend to be created for very specific purposes. However, Integrated Valuation of Ecosystem Services (InVEST), a suite of software models that can be used to map and value ecosystem services, has been found to provide significant and comprehensive data for future research.

The Use of InVEST

InVEST was developed by the Natural Capital Project (NatCap) in collaboration with Stanford's Woods Institute for the Environment, The Nature Conservancy, World Wildlife Fund, and University of Minnesota's Institute on the Environment (Sharp et al., 2014). The software has been used in a wide range of applications ranging from informing base management on suitable military environments to producing data for the US Department of Defense to use in their freshwater conservation research on the river ecosystems of Patagonia. Bagstad et al. (2013) compared InVEST with another ecosystem services modeling tool, Artificial Intelligence for Ecosystem Services (ARIES), when modeling important ecosystem services in the San Pedro River watershed in southeastern Arizona, USA, and northern Sonora, Mexico. The InVEST models were found to be comparatively feasible to those produced by ARIES, and were more intuitive, especially after completion of the data management process. Baral et al. (2014) conducted a spatial assessment using an InVEST biodiversity model to quantify and map habitat quality and biodiversity in north-central Victoria, Australia. Although the results were found to be different from those of the government, the software showed considerable potential, especially with regards to its illustrations of the operational tools. Geng et al. (2014) demonstrated changes in water yields across three scenarios; the changes were the result of the impact of land use/land cover change (LULC) and precipitation. InVEST was deemed to be suitable and explicit for the watershed scale level necessary for this analysis.

InVEST Models for Ecosystem Services of Agricultural Lands

InVEST provides a wide range of models that can be applicable to specific research interests. This research chose five models involving ecosystem services relative to agricultural lands. These included models of: nutrient retention, sediment retention, water yield, pollination abundance, and habitat quality. Together, they highlight the abundance of ecosystem services that can be provided by agricultural lands, and are typical of the fundamental ecosystem services that agricultural lands should offer, regardless of the types of agricultural activities and products involved. Other InVEST models, such as hydropower, managed timber, and aesthetic value from viewsheds, tend to relate more to specific types of agricultural lands, and thus were not appropriate for this endeavor to quantify the ecosystem services provided by all agricultural lands in Galveston County.

InVEST runs as a standalone model or an additional tool available through GIS. The straightforward interface makes the program intuitive and easy to use. After inputting the required data, the process is completely automated. The most important part is the data preparation process; careful data preparation is of critical significance. The software requires specific file types and formatting to yield complete results. The majority of the models in this software package utilize the biophysical characteristics of the study area's landscape as their base data, including land use/land cover (LULC), digital elevation models (DEMs), precipitation, and evapotranspiration. The results are generated at the watershed level, with some outputs reported in raster format (according to the cell size of the inputs).

Study Area and Data

This study maps and quantifies ecosystem services for agricultural lands in Galveston County, Texas, USA (see Fig. 2). Located approximately 50 miles southeast of Houston, Galveston County is part of the Houston-Sugar Land-Baytown metropolitan area, which is one of the ten most populous metropolitan statistical areas. It had the fastest growing population from 2000 to 2010 at 26.1% (U.S. Census Bureau, 2010). In the past several decades, it has seen continuously expanding urban sprawl that has rapidly transformed the surrounding land into developed, mix-used properties. Galveston's agricultural lands have experienced the most change, as compared to other types of land cover (see Fig. 3). According to the National Oceanic and Atmospheric Administration (NOAA, 2014), the agricultural lands in Galveston were approximately

16,177 hectares in size in 1996. By 2010, that number had decreased to 14,271 hectares, representing an 11.78% loss. Among all of the land cover classes, agricultural lands were most often changed to developed lands; the amount was measured at 1,813 hectares. During the same time period, only 518 to 777 hectares of forested lands, grasslands, shrublands, and woody wetlands were developed. Thus, lands that had inherently provided benefits to the environment, and more specifically to humans, in the form of ecosystem services were critically affected.

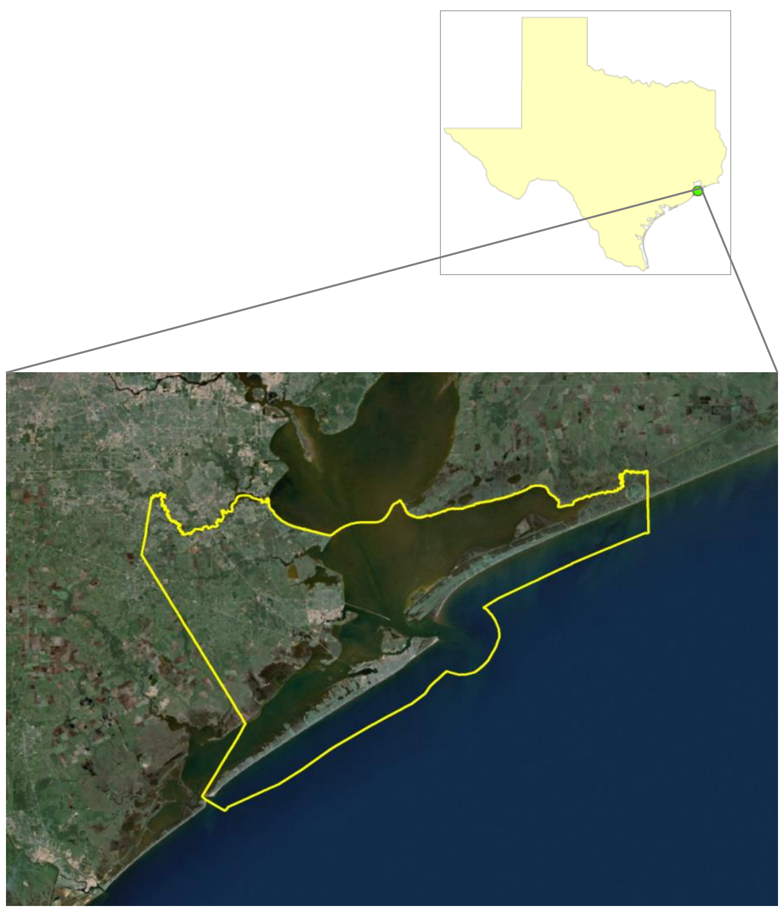

Fig. 2. Satellite imagery of Galveston County, Texas, USA.

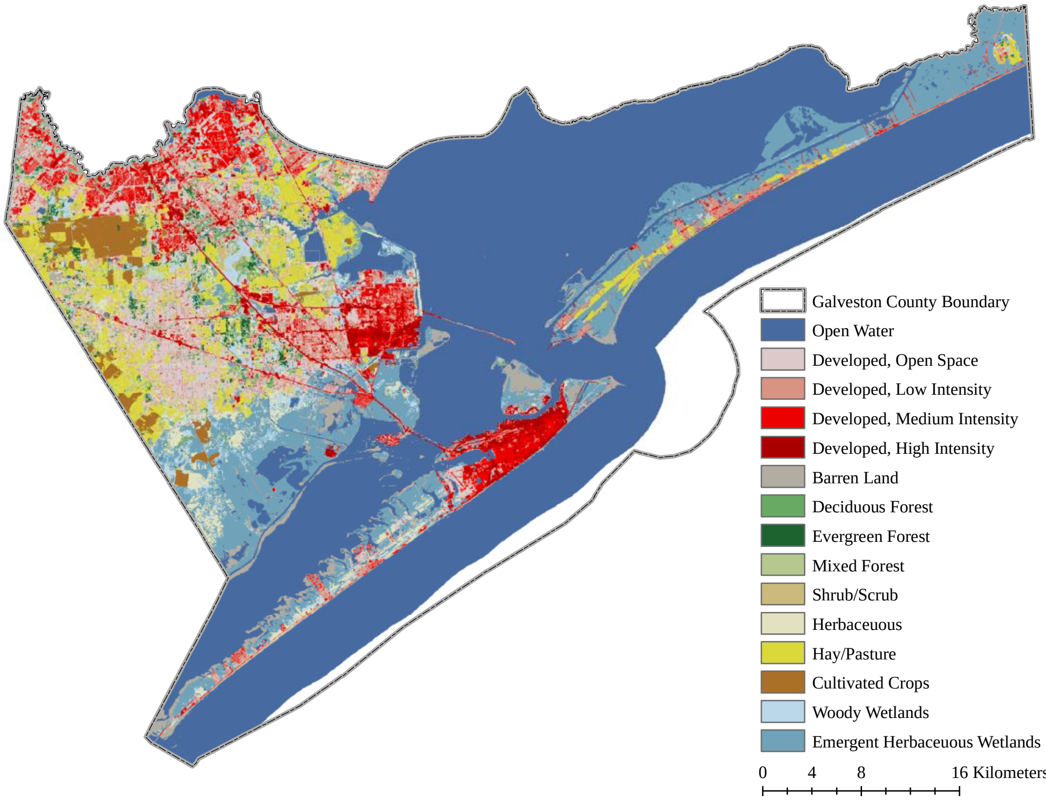

Fig. 3. Map of Galveston County LULC pattern for 2011, created from the data of Homer et al. (2015).

The ability to quantify these ecosystem services and estimate the specific value provided by each would allow for the development of tangible goals and plans. A restoration plan developed by the Texas Sustainable Coastal Initiatives is one ongoing effort to help create a resilient coastal community in this area. Understanding the amount and value of each ecosystem service provided by the land would allow for policy and decision makers to prioritize and draft more effective strategies that could best utilize the available natural resources (i.e., ecosystem services). Such steps would also help restore any degraded services, while comprehensively sustaining and protecting those already in existence.

Water Yield Model

The InVEST water yield model simulates the annual average water yield by considering the biophysical data for the landscape of interest. The model relies on LULC changes (considered to be very influential on other changes), which include water supply, water quality, and hydrological cycle (Sharp et al., 2014). Changes in landscape can affect evapotranspiration, hydrological processes, and even hydropower production. The software utilizes the following data inputs: LULC, root-restricting layer depth, precipitation, plant-available water content, average annual reference evapotranspiration, subwatersheds, biophysical characteristics that characterize LULC and the associated evapotranspiration indexes, root depth for each land use class, and an evapotranspiration coefficient for each LULC class. For simplification, InVEST combines groundwater and surface water movement, assuming that both groundwater and surface water follow the same flow, even though groundwater eventually reaches streams and may be discharged as base flow (Bagstad et al., 2013).

The InVEST water yield model is constructed to serve as the basis for other water-related ecosystem services models. These include both nutrient and sediment retention models (covered later in this chapter). The water yield model simulates the total and average water yields at the sub-watershed level. The model is based on the Budyko curve (Budyko, 1971) and annual average precipitation. It first calculates the annual water yield $Y(x)$ for each pixel on the landscape x, using the following formula:

$$Y(x) = \left(1 - \frac{AET(x)}{P(x)}\right) \cdot P(x)$$

where $AET(x)$ denotes the annual actual evapotranspiration for pixel x, and $P(x)$ is the annual precipitation for pixel x.

The evapotranspiration portion of the water balance, $\frac{AET(x)}{P(x)}$, is calculated as follows (Zhang et al., 2004):

$$\frac{AET(x)}{P(x)} = \frac{1 + \omega(x)R(x)}{1 + \omega(x)R(x) + \frac{1}{R(x)}}$$

where $R(x)$ is the ratio of potential evapotranspiration to precipitation. It is defined as follows (Budyko, 1971):

$$R(x) = \frac{K_c(l_x)ET_0(x)}{P(x)}$$

where $K_c(l_x)$ is the plant (vegetation) evapotranspiration coefficient associated with the LULC l_x of pixel x, and is largely determined by the vegetation characteristics of the LULC of that pixel.

The variable $\omega(x)$ is a non-physical parameter used to characterize the natural climate-soil properties, and is calculated as:

$$\omega(x) = \mathrm{Z}\frac{AWC(x)}{P(x)}$$

where $AWC(x)$ is the plant-available water content (in mm) that can be held, and is related in the soil for use by plants. This can be estimated as the product of the plant-available water content and the minimum of the root-restricting layer depth and root depth. Z is the “seasonality factor” that represents the pattern of local precipitation and seasonal distribution.

The required inputs for the water yield model data used in this research were acquired from various sources. Several steps in GIS were then completed to pre-process the data as inputs for InVEST. The projection for all of the layers examined by this research was the NAD 1983 UTM State Plane; the zone was the Texas South Central FIPS 4204. The unit of measurement was the meter. A cell size of 30 meters was used for all of the grid layers.

Additionally, a *DEM* was downloaded from the National Map Viewer and Download Platform (USGS, 2013). The DEM layers were then projected and merged into a single layer. Next, any missing data and sink holes in the layer were filled. Finally, the layer was converted into a raster file format (.tif) for use as an input for the Digital Elevation Model. The value for *precipitation* was acquired from the USDA Geospatial Data Gateway (USDA, n.d.). It originally came in inches, and thus had to be converted to millimeters (as required by the model) before conversion to the .tif format. The value for *evapotranspiration* came from the Consortium for Spatial Information (Zomer et al., 2007; Zomer et al., 2008), which provided this research with mean annual average evapotranspiration data for the years 1950 to 2000. These data had to be clipped to the size of the DEM layer before being converted into the .tif format. *Root restricting layer depth* was extracted from the Gridded Soil Survey Geographic Database (gSSURGO), a more refined format of the standard USDA-NRCS Soil Survey Geographic (SSURGO)

Database product, which was acquired for this research through the USDA Geospatial Data Gateway (USDA, n.d.). The data was converted from centimeters to millimeters and then exported as a new raster format layer for processing. *Plant Available Water Capacity (PAWC)* was also extracted from the gSSURGO dataset. A calculation was done to find the ratio of the Available Water Storage (*AWS*) data (specifically, "aws0_999") and the thickness used in the AWS calculation "tk0_999a." AWS provides "available water storage estimate[s] in total soil profile, which is the volume of plant available water that the soil can store in this layer based on all map unit components" (i.e., the weighted average), given the thickness of the soil components used in the total soil profile (USDA NRCS, 2011). Once the PAWC values were calculated, the data was joined with the raster data (the map units of the soil data) before being converted to a .tif format. *Land use/land cover (LULC)* data was acquired from the Crop Data Layer (USDA, 2012). The data were clipped to the appropriate extent and then converted to the .tif format. Some 43 land cover classes, according to their agricultural classifications, existed in the three watersheds of the study area. Using the attribute table for this land cover layer, a biophysical table (a required input for the model) was constructed (Appendix A, Table A2). During this process, the biophysical coefficients pertaining to each land cover class were generated. These included the land use codes (*lucode*), descriptive name of each LULC class (*LULC_desc*), binary values for the vegetated land (*LULC_veg*), maximum root depth for the vegetated land classes (Canadell et al., 1996), and a plant evapotranspiration coefficient (K_c) for each LULC class (Food and Agriculture Organization of the United Nations [FAO], 2002). The *seasonality factor (z)* is a constant that characterizes the patterns and seasonality of precipitation. For this research, it typically ranged from 0 to 20; the value can be calculated from:

$$Z = \frac{(\omega - 1.25)P}{AWC}$$

The average value of ω was determined to be 4.15, and derived from an existing study (Xu et al., 2013). The average values for P and AWC were calculated to be 1307.42 and 209.66, respectively. Hence, the Z constant was 18.08. As suggested by Budyko curve theory, a high Z value is indicative of a low sensitivity of the model to Z, and that the area has a very high aridity index (Zhang et al., 2004; Sharp et al., 2014). Appendix A, Table A1 shows a summary of the data as inputs for the InVEST models.

Nutrient Retention Model

Generally, a nutrient retention model produced by InVEST seeks to quantify the nutrient pollutants produced from runoff using the data on water yield (from the water yield model), LULC, nutrient loading and filtration rates, and the flow accumulation value. The model estimates either the phosphorus or nitrogen export coefficient, based on the vegetation types and the soil's capacity to retain the nutrients. The average amount of water yield per pixel was used in this research as an input into the model; it calculated the runoff index to identify the spatial heterogeneity influencing the phosphorus and nitrogen exports (Qiu and Turner, 2013). This index was then combined with the export coefficient to derive the adjusted loading values for each cell. The amounts of phosphorus and nitrogen retained in each cell were calculated from the "allowed" pollution in the water, and given a threshold value determined by the allowed annual load for the pollutant and the number of pixels in each subwatershed.

The model used some of the same inputs as the water yield model (DEM, precipitation, evapotranspiration, depth to root, PAWC, LULC, and watersheds), along with specifications on hydrological characteristics, including: additional nutrient loading and vegetation filtering values for each LULC class in the biophysical table, a water purification threshold table, and the threshold flow accumulation value. *Nutrient loading* (*load_n* and *load_p*) was determined by the nitrogen or phosphorus export coefficients, which are potential loadings of such nutrients that can, to different degrees, impair water quality (Sharp et al., 2014). The values were derived from the mean phosphorus and nitrogen export coefficients pertaining to each LULC class, published by the Wetlands Regulatory Assistance Program of the US Army Corps of Engineers (Lin, 2004). The *vegetation filtering value (eff_n* and *eff_p)* was a 0 to 1 integer calculated as a percentage of how much each specific LULC class could retain nutrients flowing into the cell from an upslope (Sharp et al., 2014). The values were identified from the Biophysical Parameter Database (The Natural Capital Project, 2013). Table A2 in Appendix A shows the biophysical table used for this research, including the nutrient loading and vegetation filtering values. The *water purification table* indicates the total critical load or threshold allowed for the nutrients of interest – in this research, nitrogen (*thresh_n*) and phosphorus (*thresh_p*) – in each watershed (Sharp et al., 2014). The threshold values were determined to be 2 kg/yr and 3 kg/yr, respectively (Lin, 2004; Baron et al., 2011). The *threshold flow accumulation value* defines the number of cells that must be accumulated before the water body can be considered a stream. This helps in identifying the stream layer, which is necessary for the calculation of the model. The value for this research was determined to be 1,500; it was derived from a GIS tool.

Sediment Retention Model

Sedimentation and erosion are important processes for ecosystem services in agricultural lands. Excessive sedimentation and erosion can lead to water quality problems, land degradation, and flooding. These, in turn, can affect agricultural productivity, increase flooding and pollution transfer, and threaten infrastructures (Sharp et al., 2014).

This model evaluated the capacity of the study land to retain sediment, and helped the researchers to understand sediment retention as an indicator for analysis and a determining factor in decision-making processes. Examples have shown that changes in LULC can have a significant impact on sedimentation and erosion. Land use conversion to impervious surfaces that is the result of rapid urban growth can potentially wipe out vegetation cover vital for retaining sediment and preventing excessive erosion in the land. Understanding how well the land retains sediment can help inform decision makers deciding issues regarding development, restoration, and conservation projects.

This model used the Universal Soil Loss Equation (USLE), which was developed by Wischmeier and Smith (1978) and operates at the pixel scale. The calculation employed information about the LULC patterns, soil properties, digital elevation model, precipitation, and climate data. In general, pixel-scale calculation provides an opportunity for users to identify the spatial heterogeneity of the biophysical factors of the water yield, such as precipitation, vegetation type, and soil type (Sharp et al., 2014).

In addition to existing DEM, LULC, and watershed data, a *rainfall erosivity index* (*R*) was employed to indicate the erosion potential of each cell, based on the intensity and duration of rainfall on the landscape (Sharp et al., 2014). The data used were the mean annual *R*-factors from 1971 to 2000 (NOAA, 2014); these were linked to the watershed data via HUC-8 units. A unit conversion was necessary to translate the data from US customary units to MJ.mm $(ha.h.yr)^{-1}$ before converting the data into a raster file for processing. *Soil erodibility* (*K*) was used to measure the susceptibility of the study soil to erosion from rainfall and runoff (Sharp et al., 2014). The data were generated from the Soil Data Viewer, a built-in extension of GIS (ArcMap) that creates soil-based thematic maps (USDA, 2011). Specific gSSURGO data for Texas was used in the Soil Data Viewer to generate a *K* factor map; this map was eventually converted into a .tif file format for further processing. Additional data required for the biophysical table included cropping management factors such as the cover-management factor used for the USLE (*usle_c*), which compared cropping and management practices to the standard fallow plot, and a support practice factor for the USLE (*usle_p*); the latter estimated the conservation practices in the management system, specifically for the effects of contour plowing, strip-cropping, or terracing to straight-row farming up and down a slope (Sharp et al., 2014). Both values were derived from existing studies (Stone and Hilborn, 2004; FAO, 2002) and the Biophysical Parameter Database (The Natural Capital, 2013).

Habitat Quality Model

The habitat quality model generated the estimated states of habitat degradation and quality across the various study landscapes. Habitat quality and its extent are often regarded as proxies for use in measuring biodiversity (Sharp et al., 2014). The model for this research employed data on LULC, sensitivities of the LULC types to threats, and the intensity and distribution of any specified threats. One assumption researchers made about this model was that larger areas with higher levels of habitat quality would support more flora and fauna species. In other words, the levels of biodiversity would be high. On the other hand, smaller areas with lower levels of habitat quality would contain comparatively less biodiversity (Baral et al., 2014).

Biodiversity is a vital indicator of the sustainability of an ecosystem. For decision makers, understanding the spatial distribution and richness of species available across a particular landscape can help them to make more informed decisions regarding land use and resource management, which can then bring about appropriate conservation strategies designed to maximize biodiversity (Sharp et al., 2014).

The model focused specifically on threats that could potentially affect the habitats within the study area. A *current LULC map* with a 5-kilometer buffer was generated during the preparation of this model. The buffer was used because there might have been potential threats at the greatest maximum threat distance that otherwise would not have been unaccounted for, resulting in an overestimated habitat quality score (Sharp et al., 2014). The *threat data table* included all threats to the study habitat. Compilation and assessment of the threats specific to Galveston County were performed based on studies by The Nature Conservancy of Texas (2001), Jarvis et al. (2010), and McPherson et al. (2008). Table 2 shows the specific threat, maximum distance at which the threat affects habitat quality (measured in km), and weight (ranging from 0 to 1), which is the impact of each threat on habitat quality (with respect to the other threats). A *sensitivity table*, indicating whether each LULC class was considered to be a habitat and if such habitat was sensitive to each threat, was also generated. *Sources of threat maps* were also generated for the threats specified in this research. The National Land Cover Database (NLCD) land cover change data from 1992 to 2011 (Houston Galveston Area Council [HGAC], n.d.) was used to process and create this dataset, which represented threats based on changes to the LULC (e.g., conversion of lands to developed lands).

Table 2
Threat assessment as an input table for the InVEST habitat quality model

Threat	Indicator	Max. Distance (km)	Weight (0 to 1)
Conversion to agriculture	Land cover change (to "cultivated")	5	1
Residential and urban Development	Land cover change (to "developed")	5	1
Wetland loss	Land cover change (to "wetland")	5	0.75
Loss of green vegetation	Land cover change (from "forest")	5	0.5
Oil and gas	Active oil and gas leases	5	0.5
Hazardous waste	Hazardous waste sites (TRI and Superfund)	5	0.75

Pollinator Abundance Model

Crop pollination is a valuable ecosystem service for agricultural lands. Agricultural production depends upon pollination to grow crops that rely on animal pollination. Pollination benefits at least 87 of the 115 globally important crops (Klein et al., 2007; Sharp et al., 2014). With the information on crop pollination provided by InVEST, farmers and decision makers will be able to develop better farming strategies, clearly understand agricultural yields and productivity, and accurately decide the most viable farming options. If land is to be conserved or developed, the cost and benefits can be weighed such that the individuals involved in the project will be able to make the most informed decisions regarding land management. If the level of pollination is high, such decision makers might consider preserving the land or growing more suitable crops.

The InVEST pollinator abundance model estimates the availability of pollinators' nest sites, floral resources, and bee flight ranges (Sharp et al., 2014). Bees are considered to be the most important animal pollinators. Honeybees and bumblebees, two of the most widespread pollinator types, were used as the main pollinators in the model developed for this research. The model required LULC data with specifications on agricultural LULC classes to represent the agricultural parcels benefitting from bee pollination. The characteristics of the pollinator species were required to be input as a table that explained the pollinator species, nesting type, pollinator activity categorized by floral season, and average distance the species had to travel to forage on flowers. The relative availability of the nesting type and abundance of flowers with respect to each LULC class were also required.

The pollination abundance model did not require several datasets to be input. The model, however, did requests additional specifications on the LULC classes used for agricultural lands suitable for pollination. Then, the pollinators' (honeybees and bumblebees in this research) relative availability of their respective nesting types (Ricketts et al., 2006) and floral abundance pertaining to each LULC class (Greenleaf et al., 2007) were input as a *land cover attributes table*. The species name, nesting guild, pollinator activity by floral season, and average travel distance of each species to flora (Greenleaf et al., 2007) were determined and input into the *guilds table*.

CHAPTER IV

METHODOLOGY

Hedonic Price Model

Hedonic price models are commonly used as a valuation method associating value with the environment. Property transactions are compound commodities, and regarded as amenity values because people are willing to pay for the quality of their living arrangements (Kong et al., 2007). In hedonic price models, different attributes contribute to the value of a property (which is measured either by its sale price or appraisal value). Generally, these attributes are categorized into structural, environmental, and neighborhood characteristics. By using these attributes as proxy variables, environmental attributes can be estimated in hedonic price models. The value of an environmental attribute is quantified by estimating the marginal implicit price of an attribute, which is the amount an individual would be willing to pay given a unit of change in the attribute and holding everything else constant.

The hedonic pricing model, developed by Lancaster (1966) and Rosen (1974), takes the following form:

$$P = f(X_1, X_2, \dots, X_N)$$

where P is the property price and $X_1, X_2, \dots, X_N$ are the attributes of the property. These attributes can be categorized into certain groups, including: (1) property characteristics, which are direct attributes of the property such as size and age; (2) accessibility characteristics, which define spatial attributes such as distance from the property to other amenities; and (3) neighborhood characteristics, which represent the quality of the surrounding property, such as racial contributions, crime rates, and household income. By regressing the observed prices *P* on all attributes, a marginal value of each attribute $\widehat{P}_i = \frac{\partial \hat{f}(X)}{\partial x_i}$ can be estimated. This represents the implicit price one would pay for a change in each attribute.

Functional Form and Variables

Different functional forms, such as linear, semi-log, log-log, or quadratic, can be used in hedonic price models. Consequently, a Box-cox functional form test was used to estimate the goodness-of-fit of each. Based on the estimates (see Appendix B), the semi-log model was found to be preferable. Natural logs were also taken for both the parcel size and neighborhood variables, since the effects of these variables were expected to decrease with their respective values (Sander et al., 2010).

$$\ln(P) = \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_i X_i$$

The dependent variable (P) was the appraisal price in 2012 for all of the agricultural land parcels in the study area. Sale price is commonly used as the standard for land value in most land valuation models. Since agricultural land transactions do not occur as often as those of residential lands, it was expected that only a small number would be reported for the study area. Moreover, the results of regression analyses are more reliable if a greater number of samples (in this case, land transactions) are used (Birch and Sunderman, 2003; Ma and Swinton, 2012). According to Tex. Tax Code §

23.04(1), the appraisal values of agricultural land, and specifically those of the Texas lands used for this research, are based on the land's capacity to produce agricultural products (Texas Comptroller of Public Accounts, 2006). As is suggested by the agricultural productivity values listed in the GCAD appraisal manual, the supply of land directly affects the (appraised) land value. Therefore, the components that comprise agricultural lands inherently include factors that influence ecosystem services both directly (e.g., nutrients in the soil, water yield, availability of pollinators) and indirectly (e.g., precipitation, evapotranspiration, PAWC). Therefore, appraisal value could potentially be used as another proxy for land value and was adopted as the dependent variable for this research.

According to the Texas property tax manual for the appraisal of agricultural land use (Texas Comptroller of Public Accounts, 1990), the law permits tax exemptions for agricultural lands that meet the following conditions:

- Land must currently be devoted to agricultural use to the degree of intensity generally accepted in that area.
- Land must have been used primarily for agricultural purposes for five of the last seven years, or five continuous years if the land is within the city limits.
- The owner files for an application to the appraisal office before May 1 of that tax year, with all of the information necessary to determine the validity of the claim.

Once granted, the land will continue to receive Agricultural Open Space appraisal status every year, unless ownership changes. Using only these types of lands allowed the model used for this research to focus exclusively on lands that were currently producing and benefiting from the environment; such lands met the study's purpose to develop a system for quantifying ecosystem services that was developed from the ways in which people valued such services.

In this research, different explanatory variables were associated with land value. Five categories were used to characterize the variables, according to their marginal contributions to the land parcel's value. The summary statistics for these variables are shown in Table 3.

This study's ecosystem services variables were based on results from the InVEST models; their quantities comprehensively reflected the estimated presence of such services. The models calculated the amounts on the watershed scale, and in general the results were reported at the pixel level. Since the InVEST results were mainly derived in cell-sized units, further calculations were conducted to generate a representative value for the ecosystem services available for each agricultural land parcel. Upon deriving the results in InVEST, an average amount – representing the ecosystem services value of each land parcel – was calculated in GIS.

Results from the nutrient retention model included the *total amount of phosphorus and nitrogen (kg/parcel) exported to a stream*. Using this as a proxy for the nutrient variables, the hedonic model was able to identify the levels these significant nutrients (specifically, phosphorus and nitrogen) and value them for agricultural productivity and sustainability. Sediment retention was associated with the value of the ecosystem services. Sediment export (tons/parcel), which is the total amount of sediment exported from each pixel to a stream, was used in the valuation model after calculating the average value for each land parcel. *Water yield* was also associated with the value of the ecosystem services. In the *water yield model*, the result (the amount of water yield) was deemed to be reliable only at the watershed scale. Therefore, an average water yield for each land parcel was calculated in GIS, and used as the value for the water yield variable in the ecosystem services category.

In terms of the *pollination abundance* variables, the *pollination abundance model* generated several results, but one that represented the effect of pollination on ecosystem services was the pollinator abundance index. This was an index of the "likely abundance of pollinator species nesting on each cell in the landscape, given the availability of nesting sites and of flower (food) resources nearby" (Sharp et al., 2014). This model reflected the level of potential agricultural land available for growing crops, and the likely level of productivity. The value is critical to lands that are expected to grow and sell an increasing amount of crops over time and, hence, be valued at a higher rate than other lands. Another result that also contributed to the value of the parcel's ecosystem services value was the *pollinator abundance for each agricultural cell* in the landscape. This value was based on the average of all of the bee species or guilds, and represented the likely average abundance of pollinators visiting each farm site. Though not entirely covering the landscape, the pollinator abundance for each agricultural cell reflected the number of pollinators present in the cells suitable for agricultural productivity. The difference between this agriculture-specific cell value and the aforementioned pollinator abundance is the number of pollinators upon which the calculation was based. The overall index only looked into an average of all of the bee species or guilds associated with each grid cell, while the agriculture-specific cells concentrated on the likely average of pollinators vising each farm site.

For the habitat model, a few notable results contributed to the ecosystem services value. These included the habitat degradation and habitat quality scores. The *habitat degradation score* measured the relative level of habitat degradation for each grid cell. A high score in a cell meant that the habitat degradation in that cell was relatively high (as compared to the other cells). Such a measurement helped this researcher identify an abundance of ecosystem services and reflect on how a habitat – a vital source of ecosystem services – might be valued in the market. In addition, the habitat quality score was also calculated in the InVEST model. Habitat quality indicated the habitat quality relative to other habitat qualities in the given landscape. The score signified whether a cell would be highly suitable for a habitat, given the threats specified during the calculation process.

The structural variables used in this study considered physical characteristics directly associated with the land itself. The parcel size (in hectares) indicated how much the land was valued based on its size, and if changes to that size would affect the land price in one way or another. Land values were expected to decrease as the land size increased. The land's improvement value was also an influence on land appraisal. Lands developed with structures tend to appraise higher, regardless of the type of land (Sander et al., 2010). This is indicative of how the appraisal formula (used primarily to appraise land values) typically relies on the physical characteristics of the land as a basis for the land price. Apart from that, improvement value could be an incentive for buyers to choose one parcel of land over another, as prospective buyers might consider such improvement to make the parcel more valuable than other lands.

Another relevant factor for the study's agricultural lands was slope. A representative slope in degrees for each land parcel was calculated from the digital elevation model (DEM) data obtained in GIS. Slope was also considered to be a productivity indication regarding how suitable the lands might be for certain geographically-challenged crops such as rice; in such cases, slope would offer various effects. For example, an appropriate slope might result in higher crop yields, better water management, and less potential for soil erosion.

Agricultural value was reported by the Galveston Central Appraisal District (GCAD). Each type of agricultural product was valued differently, based on the price and formula set forth by the GCAD (GCAD, 2012). In addition, the agricultural value and crop productivity indexes (CPI) were relevant and dependent upon each other. High CPI was seen to be indicative of a high agricultural value. Therefore, the product of the agricultural value and CPI was incorporated into this research as a variable in the valuation model.

A land parcel's *proximity to major roads* and *closet city* (measured in meters) were indicative of the accessibility of the land. Though not directly affecting the land's ecosystem services or environmental value, these variables contributed to the basis of the land value, its location, and cannot be neglected.

The *independent school district (ISD) variables* were dummy variables representing the various school districts within the county. The county's appraisal model explicitly indicates that land value is based on the school district. Different school districts have different influential factors that reflect marginal changes in land value if the land parcel is located within such a school district. When appraising a land parcel's value for this research, such influence factors were used to multiply the base land value and generate a land price unique to that particular parcel within the specific school district (GCAD, 2012).

Other land and soil characteristics were also estimated to be relative to the agricultural land prices used in the model. The *percentage of developed land in a parcel* measured the influence of developed land on the agricultural land price. The calculation was based on a ratio of the various cells of developed land over the total cells for each land parcel. The *percentage of cultivated land in a parcel* measured the influence of farmland on the agricultural land price. *Drainage characteristics* indicated how well the soil was drained, which was a vital factor in the agricultural activities quantified in this research. *Prime farmland characteristics,* identified by the USDA's soil survey data (which provided the data on soil characteristics) specified if the land was suitable for use as farmland.

CHAPTER V

RESULTS

InVEST Model Results

The five InVEST models generated quantitative outputs and maps pertaining to the defined watersheds crossing Galveston County (8-digit HUC watersheds: East Galveston Bay, North Galveston Bay, and West Galveston Bay).

Only the InVEST results that had previously been identified as indicators for ecosystem services are shown here (see Fig. 4). As indicated in the previous chapter, the focus of this valuation is on agricultural lands within Galveston County. Therefore, maps were clipped to include only Galveston County, and the quantitative results were calculated and reported only for those areas within the boundary of the defined research area.

Table 3 shows summary statistics of the ecosystem services indicators from the InVEST models, as well as other explanatory variables.

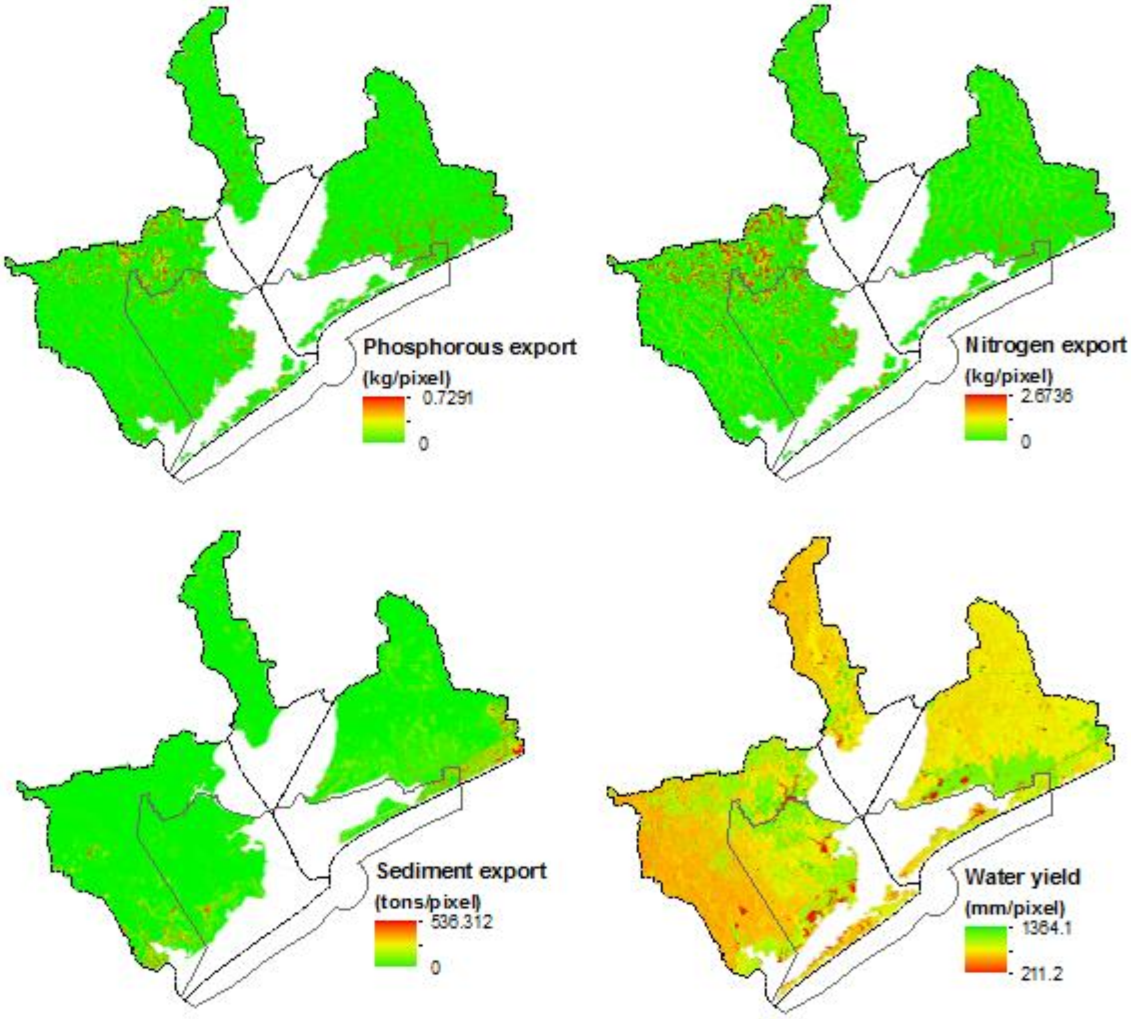

Fig. 4. Ecosystem services maps of the three watersheds (North Galveston Bay, East Galveston Bay, and West Galveston Bay) produced by the InVEST models.

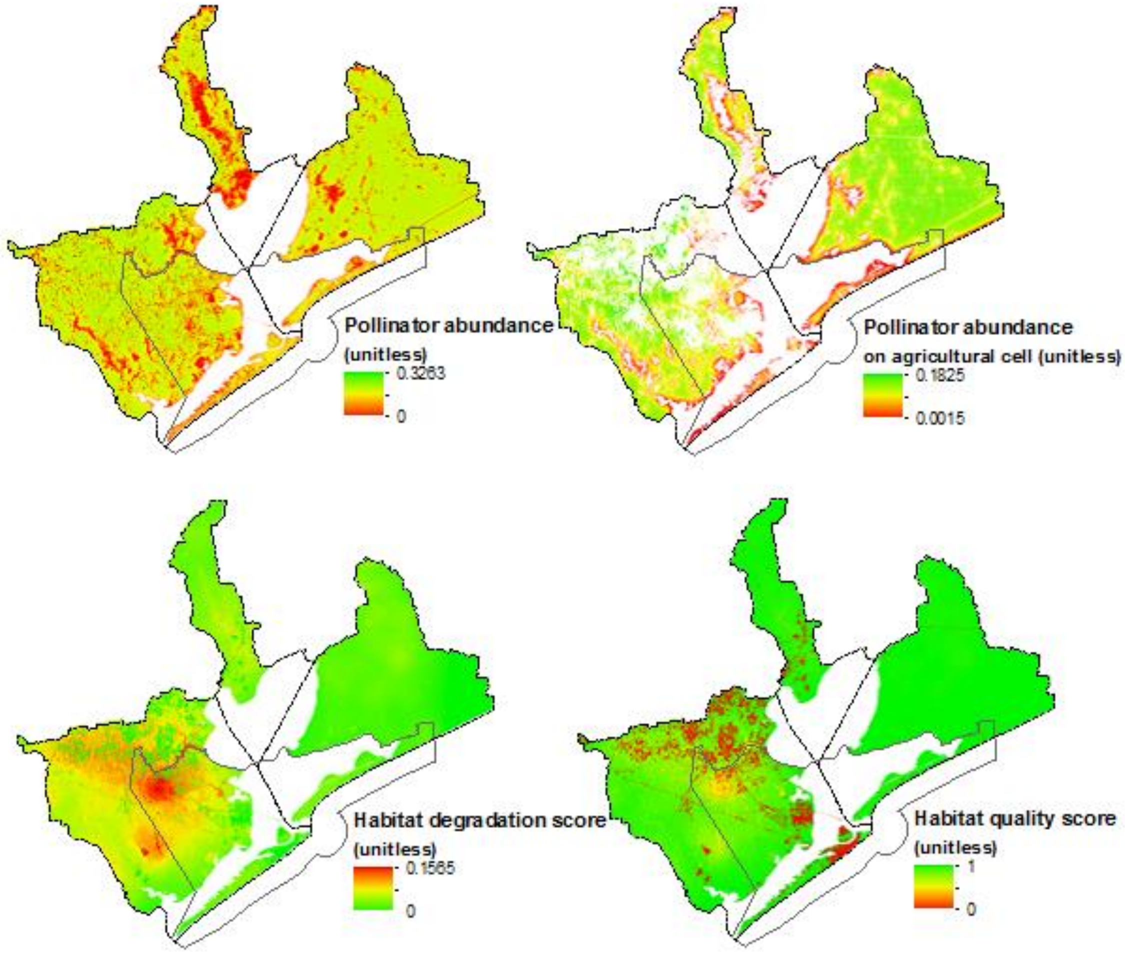

Fig. 4. *(continued)*

Results from the *water yield model* showed an attribute table listing quantitative amounts, based on the submitted inputs (Appendix A, Table A1). West Galveston Bay had the largest total area of the three watersheds at 282,497 hectares. The model calculated the annual volume of water yield as 1,983,541 1000 m^3. The mean precipitation was reported to be 1,333.77 mm per pixel. The mean potential evapotranspiration was 501.49 mm per pixel, while the mean actual evapotranspiration was 376.97 mm per pixel. The second largest watershed of the three, East Galveston Bay, spanned over 93,409.85 hectares. The water yield was approximated at 1,438,996 1000 m^3. The mean precipitation was calculated as 1,404.56 mm per pixel. The mean potential evapotranspiration and mean actual evapotranspiration per pixel were 589.21 mm and 382.07 mm, respectively. North Galveston Bay, the smallest watershed of the three, had a total area of 92,409.85 hectares. The model calculated the volume of water yield as 480,164 1000 m^3. The mean precipitation was at 1,404.11 mm per pixel. The mean potential evapotranspiration was 472.36 mm per pixel, and the mean actual evapotranspiration was 346.62 mm per pixel.

Using the results listed above, data pertaining to agricultural lands in Galveston County were generated for the valuation model. The volume of water yield for each land parcel was calculated based on the volume of water yield and estimated mean water yield in the watershed in which the land parcel resided. For agricultural lands within Galveston County, the annual volume of water yield ranged from 0 to 7,536,230 mm. The average volume of water yield for all land parcels was 515,639 mm.

The *nutrient retention model* was the product of the watershed scale maps and values of mean runoff index, total amount of phosphorus and nitrogen, total amount of phosphorus and nitrogen retained by the landscape, and total amount of nutrients exported into the stream. Since the model concentrated on nutrient exports affecting filtration and water quality, only the total amount of nutrients was considered for analysis on the Galveston County scale (see Fig. 5). To calculate results on the watershed scale, phosphorous export values were estimated at 21,992 kg, 3,559 kg, and 17,182 kg for West Galveston Bay, North Galveston Bay, and East Galveston Bay, respectively. Nitrogen export values were 199,254 kg, 37,743 kg, and 87,729 kg for West Galveston Bay, North Galveston Bay, and East Galveston Bay, respectively. Averaging the values for each land parcel in Galveston County yielded phosphorus values ranging from 0 to 0.144 kg, with a mean of 0.00684 kg per land parcel; the nitrogen values ranged from 0 to 0.549, with a mean of 0.0519 kg per land parcel.

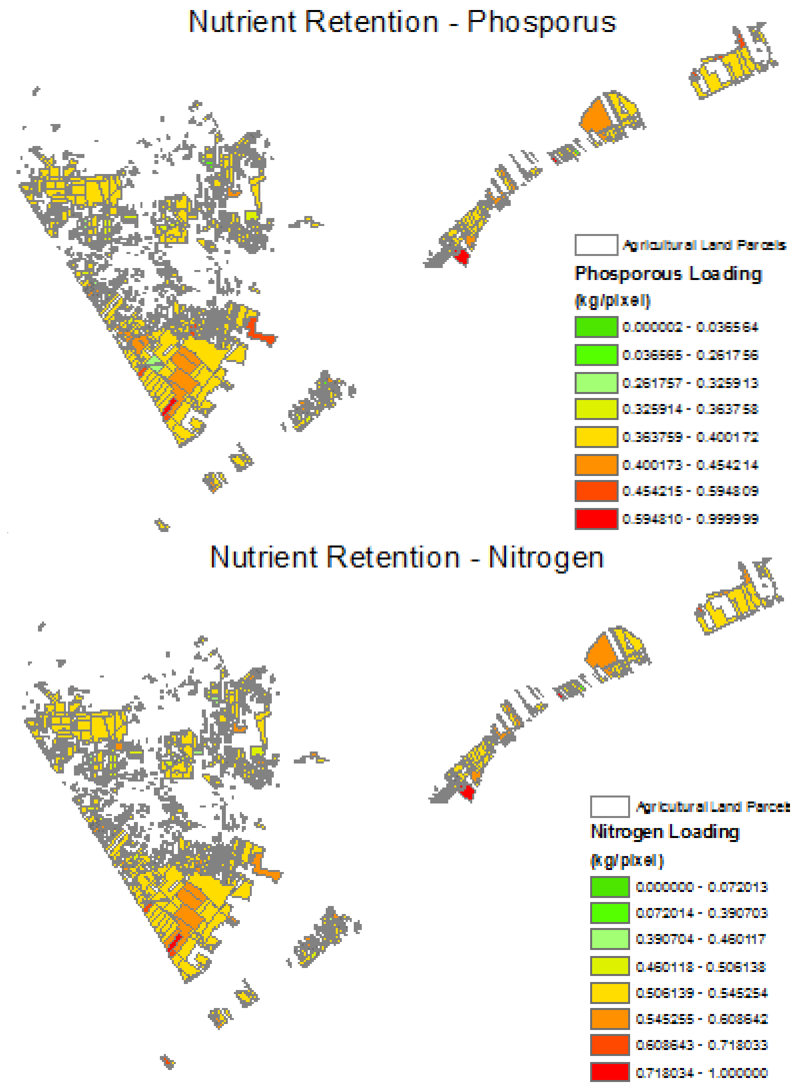

Fig. 5. InVEST nutrient retention results: the phosphorus and nitrogen loading (into streams) in agricultural lands in Galveston County, Texas.

The *sediment export model* showed the amount of sediment exported to streams to be 524,498 tons, 52,304 tons, and 809,444 tons for West Galveston Bay, North Galveston Bay, and East Galveston Bay, respectively. The average value of the sediment export pertaining to each agricultural land parcel for Galveston County ranged from 0 to 7.2 tons, with a mean of 0.185 tons (see Fig. 6).

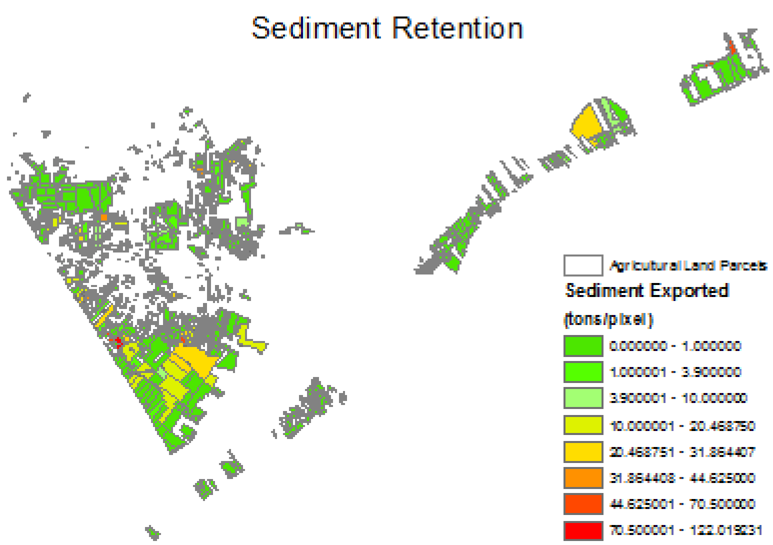

Fig. 6. InVEST sediment retention results – sediment exported (into streams) in agricultural lands in Galveston County, Texas.

The *pollination model* generated two results of interest to the present study (see Fig. 7). The first was the pollination abundance index. The range of this index was between 0 and 1, and the model yielded an index of 0 to 0.326. The higher index indicated a greater abundance of pollinator species. For agricultural land parcels in Galveston County the values ranged from 0.0647 to 0.195, while the mean was 0.142. Another indicator, *pollinator abundance in agricultural cells*, identified the pollinator abundance for each agricultural cell, based on the average of all bee species. In the three watersheds, the values ranged from 0.00149 to 0.183; the values pertaining to agricultural lands in Galveston County spanned from 0 to 0.162, with a mean of 0.117.

The *habitat quality model* showed two values in the results that were useful as indicators for ecosystem services (see Fig. 8). They were the habitat degradation score and habitat quality score. The habitat degradation score contained values from 0 to 0.156 (the maximum was 1). Calculating values for agricultural lands in Galveston yielded scores from 0.00681 to 0.0796, with a mean of 0.0391. The habitat quality score had values from 0 to 1; the agricultural lands showed values from 0.662 to 1, with a high mean value of 0.992.

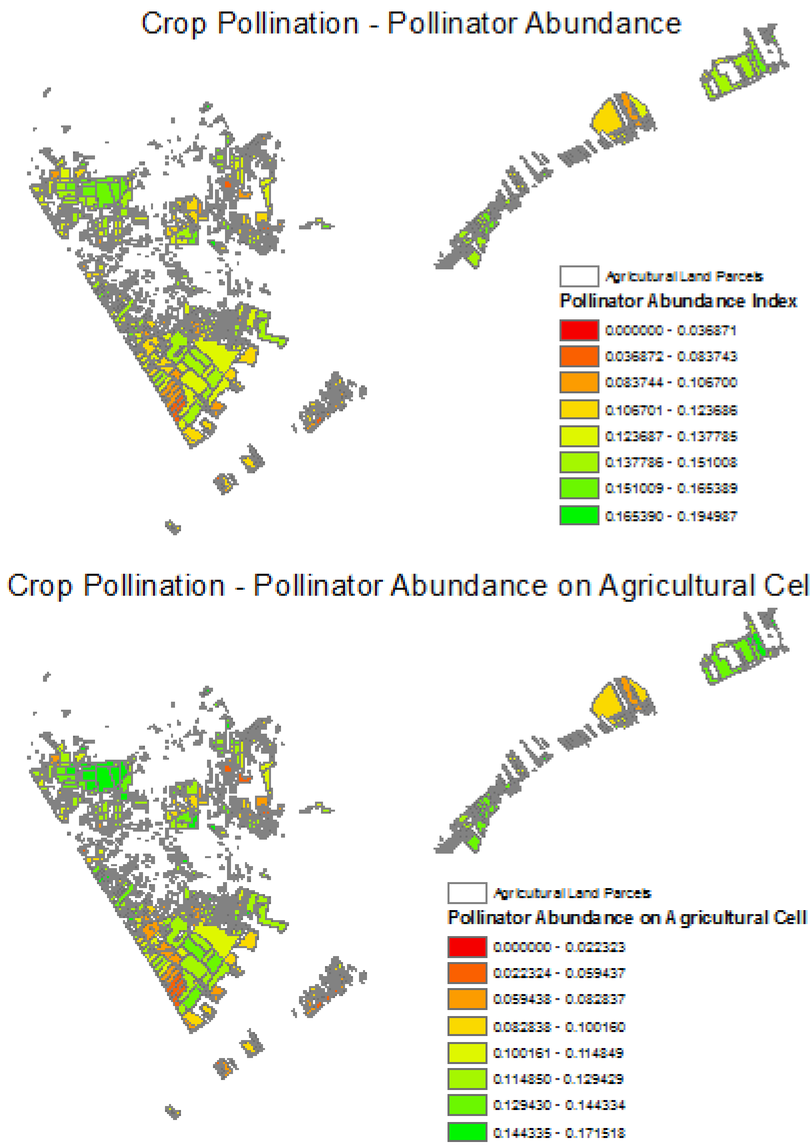

Fig. 7. InVEST pollinator abundance results: pollinator abundance indices for agricultural lands in Galveston County, Texas.

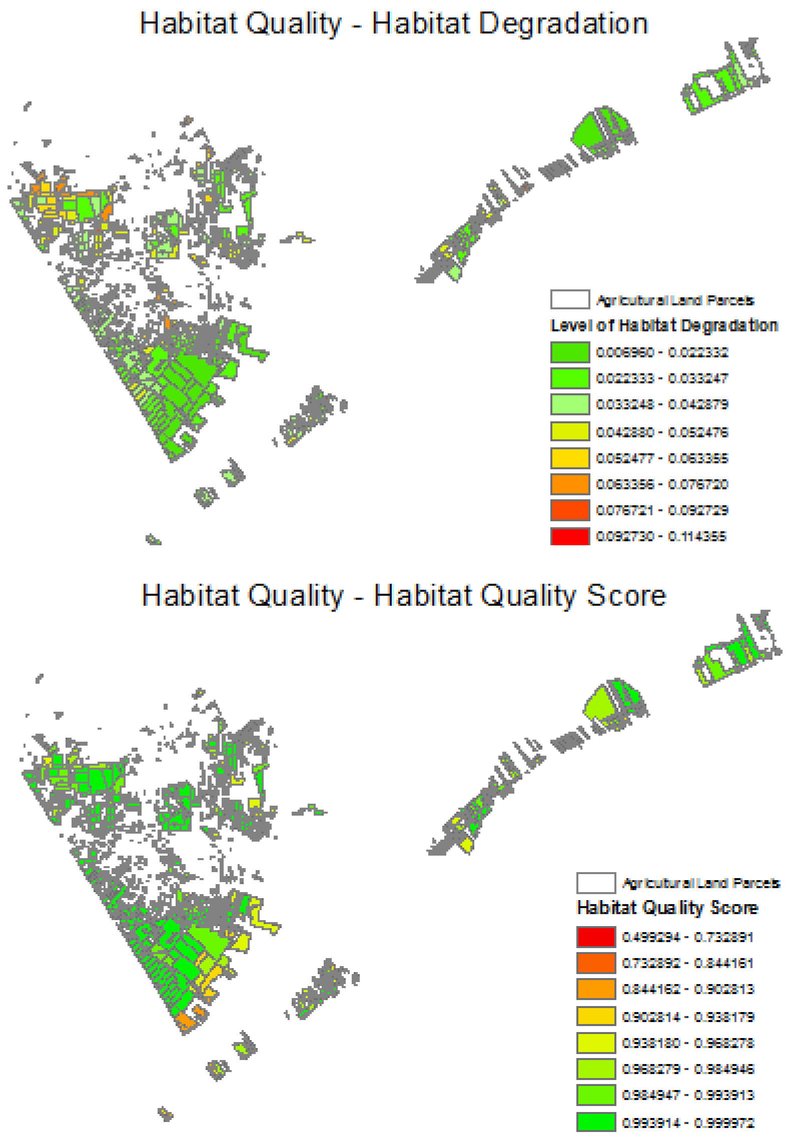

Fig. 8. InVEST habitat quality results: habitat degradation and habitat quality scores for agricultural lands in Galveston County, Texas.

Table 3
Descriptive statistics for appraisal model variables for 1,112 parcels located in Galveston, Texas in 2012.

Variable	**Mean**	**Std. dev.**	**Min.**	**Max.**
Structural variables				
Appraisal value (2012 US$)	195,793	647,700	280	9,601,350
Appraisal value/ha (2012 US$)	22,071	34,664	107	400,654
Parcel size (ha)	21.4	66.6	0.0387	966
Slope (degrees)	0.160	0.204	0	3.03
Improvement value/ha (2012 US$)	1,751	10,710	0	235,776
Ecosystem services variables from InVEST				
Water yield (mm)	166,232	515,639	0	7,536,230
Phosphorous export (kg)	0.00684	0.0159	0	0.144
Nitrogen export (kg)	0.0519	0.086	0	0.549
Sediment export (tons)	0.185	0.506	0	7.12
Pollination abundance index (unitless)	0.142	0.0193	0.0647	0.195
Pollination abundance index for each agricultural cell (unitless)	0.117	0.0357	0	0.162
Habitat degradation score (unitless)	0.0391	0.0118	0.00681	0.0796
Habitat quality score (unitless)	0.992	0.0228	0.662	1
Neighborhood variables				
Distance to closest city (m)	27,526	6,059	14,000	51,167
Distance to nearest major road (m)	1,365	1,348	33.2	8,491
Production and development variables				
Crop productivity index (CPI, unitless)	0.430	0.120	0.00472	0.545
Agricultural value/ha (2012 US$)	188	170	0	3,709
Developed land % of parcel (ratio)	0.283	0.243	0	0.947
Cultivated land % of parcel (ratio)	0.276	0.262	0	0.999
Moderately well drained (binary)	0.237	0.425	0	1
Somewhat poorly drained (binary)	0.411	0.492	0	1
Poorly drained (binary)	0.284	0.451	0	1
All prime farmland (binary)	0.660	0.474	0	1
Prime farmland if drained (binary)	0.111	0.314	0	1
Non-prime farmland (binary)	0.229	0.420	0	1

Table 3 *(continued)*

Variable	Mean	Std. dev.	Min.	Max.
Market segment variables (ISD)				
Clear Creek (binary)	0.0234	0.151	0	1
Dickinson (binary)	0.179	0.383	0	1
Friendswood (binary)	0.0207	0.142	0	1
Galveston (binary)	0.0234	0.151	0	1
High Island (binary)	0.00989	0.0990	0	1
Hitchcock (binary)	0.149	0.356	0	1
Lamarque (binary)	0.0710	0.257	0	1
Santa Fe (binary)	0.516	0.500	0	1
Texas City (binary)	0.00719	0.0845	0	1

Results of Statistical Analyses

A pair-wise correlation was used to test for interrelationships among the explanatory variables (see Appendix C). The results indicated that there was a strong interrelationship between phosphorus and nitrogen exports at 0.77. This can be explained by the basis of the calculation, which used similar inputs such as precipitation, evapotranspiration, PAWC, and LULC. However, given that the nutrient loading and removal coefficients for each nutrient were generated separately (based on the literature), there was no strong evidence that the phosphorus export was dependent upon the nitrogen export (e.g., Guildford and Hecky, 2000). Water yield and parcel size, though showing a relatively high correlation, had no specific indication or supporting evidence to show a spatial correlation. Habitat degradation was shown to be dependent upon the distance to a city. The positive correlation, however, could not be fully described because more developed land that was closer to the city would be expected to be highly degraded. Therefore, there is no clear indication as to how these two variables interact. The interaction variable between agricultural value and CPI was highly correlated with the agricultural value. The effect was justified, since the interaction variable would be expected to correlate with its own variables. CPI also was shown to have a high negative correlation with one dummy variable related to prime farmland, non-prime farmland, which was another anticipated phenomenon regarding the correlation between the dummy variables and other variables. Ultimately, all of the variables were kept in the model.

Based on the simple linear regression results (see Table 4), the explanatory variables contributed to land price in various levels of magnitude. Most were significant at the $p < 0.01$ level, except for the pollination abundance for each agricultural cell, the Friendswood school district, and parcels that were somewhat poorly drained. The percent of developed land for each land parcel was statistically significant and contributed a positive 31.4% toward land price. Habitat degradation was associated with a 29.3% variation in land price, with the most positive contribution made by the coefficient estimate. CPI was also found to be relative to a 21.6% increase in land price. Pollination abundance contributed a positive 14.7% of the variation in land price. Slope, habitat quality, agricultural value, the product of the agricultural value and CPI, and improvement value were all associated with increases in land price, but to less effect (variations ranging from 0.74% to 5.14% in land price).

On the other hand, some variables were estimated to have negative influences on land price. ISD dummy variables relative to the Clear Creek school district were associated with a 28% reduction in land price. High Island school district was estimated to have the most significant negative impact, followed by Galveston, Hitchcock, Texas City, Lamarque, Santa Fe, and Dickinson. Parcel size also exhibited a similar level of magnitude with regards to land price reduction at 24.2%. Distance to the nearest major road followed closely behind at 19%. Water yield was shown to have only a slight influence with a 11.9% variation in land price. Prime farmland characteristics were shown to be negative and statistically significant at an 11% variation in land price.

Table 4
Simple linear regression with log-transformed land prices as the dependent variable.

Independent Variable	$\mathbf{R^2}$	**Coefficient**	**p-value**
Developed land % of parcel	0.314	3.15	0.000
Habitat degradation	0.293	62.8	0.000
ISD *(reference location is Clear Creek ISD)*	0.28		
Dickinson		-1.15	0.000
Friendswood		0.178	0.593*
Galveston		-2.73	0.000
High Island		-4.65	0.000
Hitchcock		-2.67	0.000
Lamarque		-1.45	0.000
Santa Fe		-1.18	0.000
Texas City		-1.89	0.000
Parcel size	0.242	-0.455	0.000
CPI	0.216	5.3	0.000
Distance to nearest major road	0.19	-0.566	0.000
Pollination abundance	0.147	27.2	0.000
Water yield	0.119	-0.00911	0.000

Table 4 (*continued*)

Independent Variable	**R^2**	**Coefficient**	**p-value**
Farmland	0.11		
(reference farmland class is prime farmland)			
Prime farmland if drained		-0.627	0.000
Non-prime farmland		-1.06	0.000
Sediment export	0.0917	-0.817	0.000
Phosphorous export	0.0893	-25.6	0.000
Distance to closest city	0.0754	1.67	0.000
Cultivated land % of parcel	0.0605	-1.28	0.000
Improvement value	0.0514	0.00289	0.000
Agricultural value * CPI	0.0511	0.00359	0.000
Agricultural value	0.0279	0.00134	0.000
Drainage	0.0247		
(reference drainage class is moderately well drained)			
Poorly drained		-0.321	0.003
Somewhat poorly drained		-0.156	0.116*
Very poorly drained		-2.07	0.000
Nitrogen export	0.0149	-1.93	0.000
Slope	0.0091	0.637	0.0015
Habitat quality	0.0074	5.13	0.0042
Pollination abundance on agricultural cell	0	0.226	0.844*

* Not significant at 1% level

After multiple linear regressions, the results indicated that 64.7% of the variation in land price could be explained by the model (see Table 5). The first estimation, the OLS regression, resulted in an adjusted R^2 value of 0.6454, suggesting that 64.54% of the variation in the log of land prices could be explained by the explanatory variables.

For most of the variables significant to this model, both the sign and significance were somewhat similar to those of the simple regression model; only the magnitude varied once the variables were considered together in the model.

From the step-wise regressions, the percent of developed land for each parcel was shown to have the most effect on land price at 31.4%. Habitat degradation followed at 18.5%, but still maintained a greater magnitude in the coefficient estimate than in the simple regression model. Other variables, though mostly significant, had less of a positive influence on price variation, ranging from 0.15% for agricultural value and slope to 0.279% for improvement value. Variables that remained negative with regards to their effect on land price were parcel size (at 19.7%), distance to the nearest major road (at 15.1%), several ISD variables (Hitchcock, Lamarque, and Santa Fe at 1.64%), percent of cultivated land in each parcel (at 0.47%), and phosphorus and sediment exports (at 0.63% and 0.21%, respectively). The only variable that had a sign different from its sign in the previous model was the product of the agriculture value and CPI; it was associated with a 0.14% reduction in price when added to the model. Some variables that influenced land price in the simple regression became insignificant when combined with other variables in the multiple regression model. These included nitrogen export, water yield, habitat quality, CPI, distance to the closet city, drainage characteristics, and prime farmland characteristics.

Table 5
Multiple linear regression results with a logarithmic transformation of the dependent variables and appraisal values. Only the independent variables with p < 0.1 and non-zero coefficients are shown.

Independent Variable	**R^2 added**	**Coefficient**	**p-value**
R^2 = 0.654, Adjusted R^2 = 0.647, N = 1112			
Developed land % of parcel	0.314	0.854	0.000
Habitat degradation	0.185	43.7	0.000
Parcel size	0.0487	-0.197	0.000
Distance to nearest major road	0.0303	-0.151	0.000
Improvement value	0.0279	0.0000211	0.000
ISD *(reference location is Clear Creek ISD)*	0.0164		
Dickinson		-0.163	0.369
Friendswood		0.0365	0.876
Galveston		0.0803	0.773
High Island		-0.495	0.183
Hitchcock		-0.661	0.002
Lamarque		-0.357	0.102
Santa Fe		-0.485	0.004
Texas City		0.079	0.828
Pollination abundance	0.0122	10.6	0.000
Cultivated land % of parcel	0.00470	-0.764	0.000
Phosphorous export	0.00630	-6.79	0.000
Sediment export	0.00210	-0.196	0.001
Slope	0.00150	0.324	0.023
Agricultural value	0.00150	0.00301	0.001
Agricultural value * CPI	0.00140	-0.00557	0.004
Distance to closest city	0.00130	-0.506	0.036
CPI	0.00100	0.793	0.076

Since spatial error and heteroscedasticity were of concern for modeling with spatially-related data, model diagnostics containing tests against spatial autocorrelation were used. First, Moran's I statistics were calculated. The Moran's I statistics showed that 28 out of the 31 variables were significant at the 0.001 level, suggesting the presence of spatial autocorrelation. Consequently, Lagrange Multiplier diagnostics were used to further inspect the specifications of the spatial model (Anselin, 2004; Fig. 9). The statistics indicated that both the spatial lag and spatial error models were highly significant, with the latter being almost doubly so. Robust Lagrange Multiplier diagnostics were then considered; the statistics suggested that the spatial error model was significant at $p < 0.001$. This value was considerably higher than that of the spatial lag model, which was not significant at $p > 0.05$ (see Appendix D). Thus, the spatial error model was adopted.

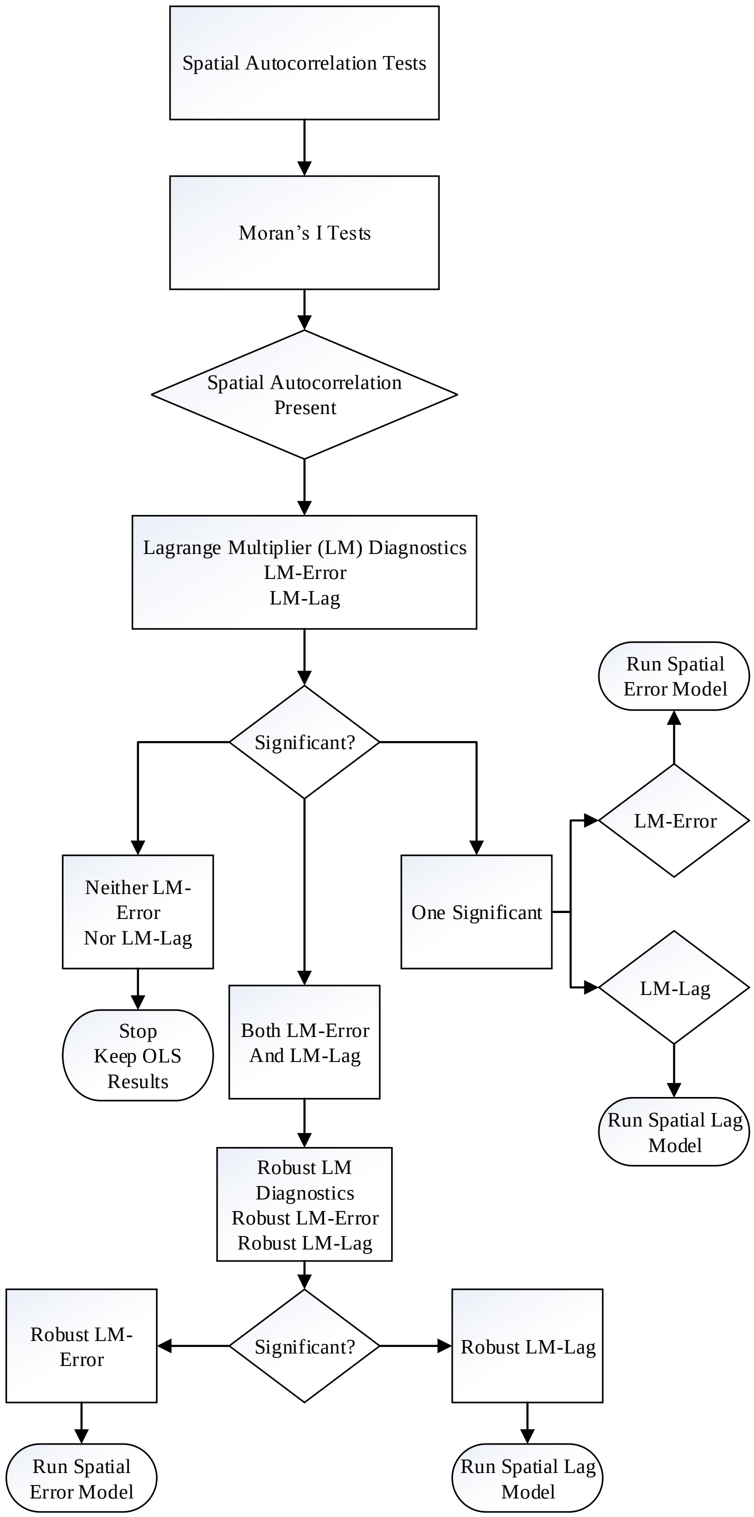

Fig. 9. Spatial autocorrelation decision model.

The first spatial error model was estimated using a maximum likelihood estimation. The results (see Table 6) showed a so-called pseudo R^2 of 0.582. The log-likelihood increased from -1,331.034 in the OLS model to -1,193.871 in the spatial error model. The Akaike Information Criterion (AIC) was reduced from 2,726.068 to 2,451.741, while the Schwarz Criterion (SC) decreased from 2,886.514 to 2,612.187, suggesting an improvement in fit from the OLS model. The spatial autoregressive coefficient (λ) was estimated at 0.7881, and was highly significant at $p < 0.00000001$.

A Breusch-Pagan test was then calculated. The resulting statistic was 184.955 and highly significant at the 0.001 level, indicating that heteroskedasticity was present in the model. Therefore, the spatial error model with generalized methods of moment (GMM) estimation and heteroskedasticity was used to correct for such an effect (Anselin and Rey, 2014). The adjusted R^2 was 0.5921, indicating adjustments in the heteroskedasticity from the previous model. The estimates (see Table 6) were close to those of the spatial error model with a maximum likelihood estimation because they exhibited almost identical coefficient magnitudes, signs, and significances, especially for the coefficients highly significant at the 0.001 level. The spatial autoregressive coefficient (λ) was estimated at 0.8178, slightly higher than that of the maximum likelihood, and was highly significant at $p < 0.0000000$.

Regression diagnostics were then performed, and adjustments were made to improve the model. Pair-wise correlation and variance inflation factors resulted in multicollinearity. Therefore, the ISD dummy variables were dropped. However, a joint F-test further indicated that the dropped variables were not significant at the 1% level, implying that the dropped variables were not jointly equal to zero. Therefore, the ISD variables remained in the model. In fact, by comparing the overall estimates from the model that contained ISD variables with the one in which the ISD variables had been removed, the models' fits (in terms of the magnitude, sign, and significance) were almost identical.

In terms of the coefficients for ecosystem services variables, increases in the habitat degradation score, pollination abundance index, and water yield were all associated with a higher land price. The habitat degradation score was positive and statistically significant at the 1% level. A 1% rise in the habitat degradation score was estimated to nearly double the land price. Using the mean land price of $22,071 per hectare and mean habitat degradation score of 0.0391, the marginal implicit price of a 1% increase in the habitat degradation score was $413,941.61 (given the estimated coefficient value of 18.755).

The pollination abundance index was also positive and statistically significant at the 5% level. For every 1% increase in the index, the land price went up more than threefold. The marginal implicit price of a 1% increase in the pollination abundance index was calculated as $76,696.73.

The coefficient estimate value for the water yield was quite small, but was statistically significant at the 10% level; a 1% increase in water yield induced a 0.13% higher land price. Using the mean land price, the marginal implicit price for the water yield was $28.69.

The other two ecosystem services variables that adversely affected the land price were sediment export and phosphorus export, as evidenced by the negative coefficients that were significant at the 5% and 10% levels, respectively. A 1% increase in sediment export lowered the value of the land by 12.13%, which yielded a marginal implicit price of -$2,677.21. A 1% increase in phosphorus export was estimated to reduce the land price more than fourfold. The marginal implicit price was equal to -$91,727.08. The coefficient for pollination abundance pertaining to each agricultural cell was positive and had a magnitude comparative to that of pollination abundance, but it was not statistically significant. The coefficient for nitrogen export was estimated to have a positive effect by an almost 15% per unit increase in the variable, but it was also not statistically significant. The habitat quality score was estimated to negatively affect the land price, but it was not statistically significant.

Production variables also contributed to changes in land price. As evidenced by the estimates, most were highly significant at the $p < 0.01$ level. Variables that positively affected land price included the Crop Productivity Index (CPI), production of agricultural value per hectare, percent of developed land in each land parcel, and the two most positive drainage characteristics. Crop productivity increased land price by as much as 86.46% per every 1% increase in the CPI. A 1% increase in developed land within a particular parcel raised land price by 80.42%. A dollar increase in agricultural value per hectare raised land price by $0.43 per hectare. Land parcels that were either poorly drained or somewhat poorly drained were priced at 16.93%, 16% higher than those parcels that were very poorly drained. Other production variables were also associated with decreasing land price. The product of the agricultural value and CPI was relative to a decrease in land price; a percent increase in the product of the agricultural value and CPI reduced land price by 0.76%. A percent increase in cultivated land within a parcel brought down land price by over a dollar. Inferior prime farm land characteristics decreased land price. A parcel that was non-prime farmland was valued 22.94% lower, while a parcel that was categorized as prime farmland if drained was valued 22.14% lower.

One type of neighborhood characteristic was also associated with a decrease in land price. A meter closer to a major road could lower the land price by more than a quarter. Distance to the closet set city, although found to be potentially positive, did not contribute to land price because it was not statistically significant.

In addition, structural variables were identified to have certain effects on land price. A 1% increase in parcel area decreased land price by approximately 11.86%. Improvement value was statistically significant at the 1% level, but was estimated to have a much less significant effect at a 0.019% increase in land price per one dollar increase in improvement value. The coefficient estimate value for slope was positive but not statistically significant.

The estimates also attributed changes in land price to market segment variables. Six out of eight school districts were statistically significant, relative to the Clear Creek district. Only the Friendswood and Texas City districts were not statistically significant. Among the statistically significant estimates, four districts (High Island, Hitchcock, Santa Fe, and Dickinson) were highly significant at the 1% level. Compared to the Clear Creek district, land prices for parcels within these significant districts were lower by almost double (per each 1% increase in their proportion) and as much as triple in the High Island district, holding everything else constant.

Table 6
Spatial error model results with GMM estimation and heteroskedasticity

Variable	Without ISD				With ISD			
	Coefficient	**s.e.**	**z**	**p-value**	**Coefficient**	**s.e.**	**z**	**p-value**
Structural variables								
Parcel size	-0.1131***	0.0220	-5.14	0.000	-0.1186***	0.0220	-5.40	0.000
Slope	0.0196	0.1528	0.13	0.898	0.0237	0.1525	0.16	0.877
Improvement value/ha	0.0019***	0.0002	9.76	0.000	0.0019***	0.0002	9.83	0.000
Ecosystem services variables from InVEST								
Water yield	0.0007*	0.0339	0.10	0.087	0.0013*	0.0543	0.11	0.089
Phosphorus export	-4.3046*	2.7355	-1.57	0.087	-4.1562*	2.7290	-1.52	0.080
Nitrogen export	0.1740	0.4662	0.37	0.709	0.1498	0.4643	0.32	0.747
Sediment export	-0.1090*	0.0606	-1.80	0.072	-0.1213**	0.0604	-2.01	0.045
Pollination abundance	4.2305**	2.1550	1.96	0.050	3.4754	2.1817	1.59	0.111
Pollination abundance on ag cell	0.7877	0.9596	0.82	0.412	0.5636	0.9567	0.59	0.556
Habitat degradation	26.6068***	6.1952	4.29	0.000	18.7553***	6.8686	2.73	0.006
Habitat quality	0.1868	1.1895	0.16	0.875	-0.0505	1.1905	-0.04	0.966
Neighborhood variables								
Distance to closest city	0.2228	0.4036	0.55	0.581	0.4757	0.4821	0.99	0.324
Distance to nearest major road	-0.2910***	0.0389	-7.49	0.000	-0.2766***	0.0394	-7.02	0.000
Production and development variables								
CPI	1.1012**	0.4724	2.33	0.020	0.8646*	0.4803	1.80	0.072
Agricultural value	0.0046***	0.0009	4.84	0.000	0.0043***	0.0009	4.56	0.000
Agricultural value * CPI	-0.0081***	0.0019	-4.28	0.000	-0.0076***	0.0019	-4.02	0.000
Developed land % of parcel	0.9304***	0.2403	3.87	0.000	0.8042***	0.2405	3.34	0.001
Cultivated land % of parcel	-1.0595***	0.2195	-4.83	0.000	-1.0868***	0.2168	-5.01	0.000

Table 6 *(continued)*

Variable	Without ISD				With ISD			
	Coefficient	**s.e.**	**z**	**p-value**	**Coefficient**	**s.e.**	**z**	**p-value**
Very poorly drained	0.0215	0.3031	0.07	0.944	-0.0845	0.3044	-0.28	0.781
Poorly drained	0.1709*	0.0943	1.81	0.070	0.1693*	0.0941	1.80	0.072
Somewhat poorly drained	0.1772**	0.0698	2.54	0.011	0.1600**	0.0697	2.30	0.022
Non-prime farmland	-0.2589***	0.0853	-3.03	0.002	-0.2294***	0.0855	-2.68	0.007
Prime farmland if drained	-0.2276**	0.1035	-2.20	0.028	-0.2214**	0.1036	-2.14	0.033
DICKINSON					-0.9349***	0.3186	-2.93	0.003
FRIENDSWOOD					-0.0572	0.4187	-0.14	0.891
GALVESTON					-1.5187**	0.6167	-2.46	0.014
HIGHISLAND					-3.5018***	0.9096	-3.85	0.000
HITCHCOCK					-1.2149***	0.3620	-3.36	0.001
LAMARQUE					-0.8236**	0.3689	-2.23	0.026
SANTAFE					-0.9596***	0.3126	-3.07	0.002
TEXASCITY					-0.6127	0.9371	-0.65	0.513
Constant	6.5448***	4.2191	1.55	0.000	5.6853***	4.1711	1.14	0.000
Number of obs. = 1,112								
Prob. >F = 0.00								
Adjusted R-square	0.6014				0.5921			

s.e. is standard error, z is z-statistics.
*** Significant at 1% level
** Significant at 5% level
* Significant at 10% level

CHAPTER VI

DISCUSSION AND CONCLUSIONS

The results of this research provided insights into how ecosystem services are valued in the market. The ecosystem services made available by agricultural lands in Galveston County varied across the landscape. However, the variables in all of the model's categories were appraised in the land price, to various effects.

Based on the InVEST results, the factors that exerted the greatest influence on the amount of water yield were LULC, precipitation, and evapotranspiration. These were the primary inputs used in the main equation in the InVEST water yield model. The results illustrated in the maps and their associated values indicated that water yield was low in both croplands and cultivated lands. This indicates that land degradation strongly affects the water supply. On the other hand, grasslands, pastures, and forests all yielded more water, in general. Human activities, therefore, play a pivotal role in influencing the supply of water, and in turn affect other ecosystem services that rely – either directly or indirectly – on that water. Certain developed lands contained higher water yields due to less infiltration, which often led to higher runoff levels. These impervious surfaces are the result of the urban development that permeates the county. As noted in Bagstad et al. (2012) and other studies, such urban development creates a series of long-term problems, including issues related to erosion, water quality, aquatic habitat, and groundwater recharge.

Beyond LULC, changes in precipitation also affected the amount of water yield. Predictably, an increase in precipitation was found to lead to a higher water yield. This coincides with Geng et al. (2014). This research used multiple scenarios in the InVEST water model, and found a strong correlation between water yield and LULC, but an even higher correlation between water yield and precipitation.

In addition, evapotranspiration was also found to affect water yield. As part of the water yield equation, evapotranspiration was seen to result in a reduced water supply. The map indicated that high evapotranspiration led to a lower water yield, even in grassland and pasture areas. On Galveston Island (where precipitation was lower and evapotranspiration was high), the water yield was generally reduced, regardless of the LULC values.

The nutrient retention model exhibited strong phosphorus and nitrogen loading around streamflows, especially at the lowest elevations. This is not surprising because when nutrients are exported downstream, runoff occurs. The most pronounced effect was in nitrogen exportation, which was more than double the phosphorus export. Sediment export did not seem to be a critical problem, except along the shoreline. This can be attributed to the typical coastal erosion effect, which can be problematic for habitat communities and ecosystem services in the area.

Pollinator abundance was shown to be widely available among the croplands, grasslands, and pastures, as was expected. Developed lands obviously affect the availability and number of these pollinators. Consequently, the ever-increasing urban growth and land-use conversion in this area could critically affect this particular ecosystem service.

The habitat quality scores indicated generally favorable conditions for specific locations. Larger patches of land received higher habitat quality scores than smaller, patchy ones. As anticipated, it was developed lands, and particularly the high-intensity developed parcels, that had the lowest habitat quality scores of all. Furthermore, some of the areas near these developed lands also seemed to be affected. The notion of habitat corridors or buffer zones may help explain the coarser-scaled effects such parcels of land have on habitat. The development effect is not confined to the specific parcel of land being developed; it also affects the surrounding areas. Habitat degradation, however, was shown to be most pronounced in croplands and attributable to the threats of agriculture, hazardous waste sites, and conversion of the land's use.

Upon completing the hedonic valuation, at least half of the ecosystem services variables were found to help explain the variations in land price, at least to a certain degree. Among the statistically significant variables, all had the anticipated sign (either positive or negative) with regards to land price. Habitat degradation was the most highly valued ecosystem services variable. Land value is the foundation of any land appraisal model. Generally, it is based on the geographical location and biophysical characteristics of the land. Location is one of the prime determining factors that dictates the value of the land, and is likely to be evidenced in this habitat degradation variable.

Coinciding with how the habitat degradation map and scores were generated in the InVEST model, this research found that the more developed the land, the higher the score and land value. As indicated by the map, habitat degradation was not spatially distributed; only certain land parcels were degraded, and only some were highly degraded. After a closer look, it could be seen that these highly degraded land parcels were located closer to the city and major roads, making them more accessible and likely to be developed or over-utilized. As evidenced by another statistically significant variable, the percent of developed land in each parcel, it was also found that more developed land produced higher land prices. The land values of highly degraded land parcels were very different from those of parcels that were not degraded, due to the coefficient estimate for habitat degradation. Therefore, the high coefficient estimate value was justified. This result may seem in conflict with the belief that agricultural lands should be assigned higher values if the lands are not degraded, but given that the appraisal model (or any appraisal model, in general) did not take into account habitat as a determining factor, such a result is not surprising. Any future improvements upon the appraisal model should therefore factor in habitat quality in a more rigorous manner.

Pollination abundance also exhibited a similar pattern; pollination abundance was concentrated in certain areas. Hence, parcels with higher land values tended to be clustered together, all other things being equal, though the magnitude for this variable was not as large as it was for habitat degradation. The pollination abundance for each agricultural cell, however, was insignificant. This is because only agricultural cells were used to calculate the pollination model. Not all cells on the initial map (on the watershed scale) were agricultural lands, and only certain specific cells were associated with pollination factors. Therefore, pollination abundance was not accounted for in land price.

All nutrient and sediment exports had the expected magnitudes and signs, though the nitrogen export was not statistically significant. Higher nutrient exports generally are indicative of less nutrition in the soil. Fertile soil is an indicator of suitable lands for farming or growing crops. Soil with less nutrition can suffer from reduced productivity and growing sessions. Therefore, lands with more nutrition (i.e., less nutrient export) should indeed have higher values. Sediment is also vital to the sustainability of the land because it helps to retain soil surfaces and hold crops or trees in place. Sediment export is also a major cause of erosion that can pollute water, creating additional adverse effects on the environment, such as flood risk (which can threaten crop production and reduce the amount of arable land) (Ma and Swinton, 2011). Therefore, less sediment export is preferable and adds more value to the land, as was indicated by the model.

The water yield model did not seem to influence land price as much as was anticipated. Although the sign and significance were as was expected (the estimate was positive and statistically significant), the magnitude was almost negligible. Water yield does have a positive influence, in that agricultural land benefits from a water supply, especially in areas such as Texas (and other areas with comparable climate conditions) where droughts and water shortage occur. As was found in Pyykkönen (2005) and Ma and Swinton (2011), irrigation and the accessibility of water could increase land price by as much as 10%. The lesser magnitude of the water yield estimate in this research could be due to how the water yield model was calculated. By using the average value of the water yield (which was calculated on the watershed scale), the water yield values may not have represented the most accurate information. Considering that the water yield should be specific to the biophysical characteristics of the land, greater refinement of the InVEST model could help improve this issue.

In terms of the production and development of land, CPI and agricultural values are pivotal factors in helping to determine land values. In this research, both were statistically significant, but CPI showed a greater level of influence. Both are well established factors that specifically determine agricultural capacity and productivity. The product of these two factors was also relevant to this research, although with the opposite effect. This negative contribution could be due to how agricultural activities in Galveston tend not to coincide with CPI data. CPI calculations are based on the physical and chemical properties of the soil, so no climatic conditions or other factors are used. The individual effects of each variable – both CPI and agricultural value – illustrate how each can contribute positively to land price.

This research's conclusions regarding one variable, the percent of cultivated land, contradict what has been found in previous research (e.g., Ma and Swinton, 2011; Palmquist and Danielson, 1989). It was expected that an increase in the percent of cultivated land would raise the land price due to the notion that supposedly favorable land would generate more agricultural productivity and income. One explanation for this negative conclusion could be that most agricultural lands in Galveston are not optimally suitable or at their full production scale, and most agricultural production tends to be limited to a select few crops (mainly rice, soybeans, nursery stock crops, and forage crops). Higher concentrations are in aquaculture and nurseries (USDA, 2012). In this research, land considered poorly drained or somewhat poorly drained had values higher than land considered very poorly drained. Lands not considered prime farmland or drained prime farmland also were valued less than all prime farmland. These findings indicate how land characteristics are accounted for in land prices.

In addition, specific characteristics of the structural variables contributed, to a certain degree, to changes in land price. Land price increased with parcel size. This could be a typical scale and marginal effect, as well as attributable to the higher transaction costs for both buyer and seller (Ma and Swinton, 2011). Improvement value was also a factor that increased land price to a small effect. For agricultural lands, improvements may not be as significant a contributing factor as they are to residential lands. Improvements come in the forms of buildings, decks, fences, etc., and those are not primary factors that dictate the value of agricultural land or its productivity.

The spatial scale of the analysis is another aspect requiring further investigation. Certain InVEST models such as water yield and nutrient retention are calculated on the watershed or subwatershed scales. The results, though generated on both the pixel and watershed levels, can best be interpreted at the watershed level (Sharp et al., 2014). Although some work has been reported at the pixel level (e.g., the water yield model in Bagstad et al. [2013]), the final evaluations have been done on the watershed scale, mainly regarding the overall changes in the model outputs, according to different scenarios. Even though there is no concrete evidence that a finer scale of analysis leads to inaccurate or misinterpreted results, keeping the analysis at the watershed level (as was intended by the model structure) might help avoid problems. If an analysis requires a significantly finer scale, then reliable methods of accurately generating results are necessary. For example, spatial statistics that utilize figures to systematically calculate spatial values and are based on existing values (e.g., creating interpolation values based on reference values calculated by the InVEST models). To implement such a procedure, more thorough research designed to determine the most appropriate method is essential. As Hein et al. (2006) explained, ecosystem services provide a wide range of services and benefits to different stakeholders, on different scales. Therefore, it is crucial to evaluate the spatial scale when formulating and conducting a valuation of ecosystem services.

In line with the spatial scale is the resolution or cell size of the data. In general, spatial data demonstrate greater detail if they are communicated in smaller cell sizes or in higher resolutions. This is, however, not the case for the watershed scale of analysis used in some InVEST models. Given that the model interpretation is generally done at the watershed level, non-drastic change in resolution, such as from a 30-meter cell size to a 50- or even 100-meter cell size, would not critically affect the results. Future comparative analyses that incorporate different spatial resolutions may help identify discrepancies – if any – in the results, and if problems exist, the cut-off point should be the point at which the most common or larger cell size could be used without compromising the results.

In an ecosystem management or policy development plan, a fine resolution may not be of the utmost interest to stakeholders or policy makers. Higher-resolution analyses will likely prove to be most useful in visualizing hotspots of ecosystem services (such as prioritized biodiversity areas) because higher resolutions will help to eliminate insignificant details from the decision making process. More appropriate levels of resolution will also aid efficiency when running models because data of a finer resolution take more computer memory and processing time. Consideration of different resolutions and the acquisition of data from various sources should both be scrutinized.

This study included ecosystem services variables that have not previously been studied. Although not all ecosystem services variables were found to be associated with land price, the results indeed indicated that the model was plausible. With further adjustments and refinements with regards to the spatial and quantitative generation of ecosystem services variables and valuation models, the results should improve.

In the future, a more detailed map and accurate values for the InVEST models should be created. Surveys of stakeholders and the operators of specific environmental programs that address each ecosystem services variable to a much finer scale could also potentially contribute to this ecosystem services research. Additionally, certain variables might become statistically significant after the elimination of measurement error. Finally, model calibration and future developments in data collection could help this research better reflect more accurate and efficient model valuation.

This research adds a significant policy implication that has not yet been emphasized: the importance of agricultural productivity and sustainable agriculture. High-level agricultural production does, undoubtedly, generate more revenue. However, intensive farming comes with a price; land that is continuously farmed eventually suffers from fewer nutrients, sediment, and the other soil components that distinguish prime farmland. Consequently, such a land eventually loses its high quality and can no longer produce at full capacity. In turn, this over-farming creates a stressful environment for pollinators and damages other habitats sustained by the land. By adhering to the tenants of sustainable agriculture that some PES programs currently advocate, not only do farmers retain the same or higher levels of production, but the land and environment are also protected. Areas that contain hotspots of certain ecosystem services can then be protected for restoration and conservation. Incentives such as PES programs should be transparent and practical so that farmers are willing to pledge participation and put the health of the ecosystem at the forefront of their farming practice. Reliable ecosystem services valuations will allow PES program to implement successful campaigns because only significant services will be visualized and concretely measured in dollars. These PES programs will also serve as additions to or replacements of taxes that farmers would otherwise have to pay for using (i.e., exploiting) the land.

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APPENDIX A

Data acquired and used in InVEST models are listed in the following tables.

Table A1
Data layers used as inputs in InVEST models. Specifications on other types of data (attributes and parameters) are addressed under each specific InVEST model in Chapter III.

Model	**Layer**	**Source**	**Resolution**	**Extent**	**Year**
Water yield	DEM	USGS National Map Viewer and Download	30 x 30 m	USGS NED n30w095, n30w096, n31w095, n31w096	2013
	LULC	Crop Data Layer, USDA	30 x 30 m	Mosaic of 4 DEMs	2012
	Root restricting layer depth	gSSURGO, USDA	10 x 10 m	Mosaic of 4 DEMs	2012
	Precipitation	USDA Geospatial Data Gateway	30 x 30 m	Mosaic of 4 DEMs	Mean annual 1981-2010
	Plant available water content	gSSURGO, USDA	10 x 10 m	Mosaic of 4 DEMs	2012
	Evapotranspiration	Zomer et al., 2007 and Zomer et al., 2008	30 x 30 m	Mosaic of 4 DEMs	Mean annual 1950-2000
	Watersheds	HGAC	Vector shapefile	3 watersheds	2013
	Subwatersheds	HGAC	Vector shapefile	3 watersheds	2013
Nutrient retention	Layers from the water yield model				
Sediment retention	Rainfall erosivity index	NOAA	30 x 30 m	Mosaic of 4 DEMs	Mean annual 1971-2000
	Soil erodibility	Soil Data Viewer and gSSURGO, USDA	30 x 30 m	Mosaic of 4 DEMs	2011
	Layers from the water yield model				

Table A1 (*continued*)

Model	Layer	Source	Resolution	Extent	Year
Habitat quality	Current LULC	Crop Data Layer, USDA	30 x 30 m	5-km buffer of original LULC	2012
	Sources of threat	NLCD, HGAC, and Texas Sustainable Coastal Initiative	30 x 30 m	5-km buffer of original LULC	20121
Pollinator abundance	Current LULC from the original LULC				

Table A2
Biophysical table as an input in InVEST models

LULC_desc	lucode	Kc	root_depth	usle_c	usle_p	load_n	eff_n	load_p	eff_p	LULC_veg
Barren	131	0.2	10	0.25	0.01	4	0.05	0.001	0.05	0
Developed/High Intensity	124	0.1	300	0.001	0.001	7.75	0.05	1.3	0.05	0
Developed/Low Intensity	122	0.2	500	0.01	0.001	7.25	0.05	1.1	0.05	0
Developed/Med Intensity	123	0.3	500	0.001	0.001	7.5	0.05	1.2	0.05	0
Sunflower	6	0.65	700	0.02	0.3	11	0.25	1.5	0.25	1
Other Crops	44	0.6	700	0.5	0.4	11	0.25	3	0.25	1
Developed/Open Space	121	0.5	700	0.01	0.001	7	0.05	0	0.05	0
Potatoes	43	0.6	1000	0.35	0.4	11	0.25	3	0.25	1
Sweet Potatoes	46	0.6	1000	0.35	0.4	11	0.25	3	0.25	1
Fallow/Idle Cropland	61	0.2	500	0.01	0.2	4	0.05	0.05	0.05	1
Aquaculture	92	1	1000	0.001	0.001	0.001	0.05	0.001	0.05	0
Open Water	111	1	1000	0.001	0.001	0.001	0.05	0.001	0.05	0
Grass/Pasture	176	0.85	1000	0.02	0.25	3.1	0.25	0.1	0.25	1
Corn	1	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Cotton	2	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Soybeans	5	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Sweet Corn	12	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Dbl Crop WinWht/Soybeans	26	0.65	2000	0.3	0.4	11	0.35	3	0.25	1
Dry Beans	42	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Peas	53	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Herbs	57	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Carrots	206	0.6	1500	0.5	0.4	11	0.25	3	0.25	1
Squash	222	0.6	1500	0.5	0.4	11	0.25	3	0.25	1

Table A2 (*continued*)

LULC_desc	lucode	Kc	root_depth	usle_c	usle_p	load_n	eff_n	load_p	eff_p	LULC_veg
Dbl Crop WinWht/Cotton	238	0.65	2000	0.3	0.4	11	0.35	3	0.25	1
Rice	3	0.65	2000	0.25	0.4	5.3	0.25	1.5	0.25	1
Sorghum	4	0.65	2000	0.25	0.4	5.3	0.25	1.5	0.25	1
Winter Wheat	24	0.65	2000	0.25	0.4	5.3	0.25	1.5	0.25	1
Rye	27	0.65	2000	0.25	0.4	5.3	0.25	1.5	0.25	1
Oats	28	0.65	2000	0.25	0.4	5.3	0.25	1.5	0.25	1
Alfalfa	36	0.7	2000	0.25	0.35	11	0.4	3	0.4	1
Clover/Wildflowers	58	0.7	2000	0.25	0.35	11	0.4	3	0.4	1
Shrubland	152	0.5	2000	0.01	0.2	2	0.5	0.011	0.5	1
Woody Wetlands	190	0.6	2000	0.01	0.2	2	0.5	0.011	0.5	1
Herbaceous Wetlands	195	0.7	2000	0.25	0.35	11	0.4	3	0.4	1
Triticale	205	0.65	2000	0.25	0.4	5.3	0.25	1.5	0.25	1
Peanuts	10	0.7	3000	0.006	0.3	10	0.45	3	0.45	1
Watermelons	48	0.7	3000	0.006	0.3	10	0.45	3	0.45	1
Christmas Trees	70	1	3000	0.01	0.2	5	0.5	0.015	0.5	1
Pecans	74	0.7	3000	0.006	0.3	10	0.45	3	0.45	1
Cantaloupes	209	0.7	3000	0.006	0.3	10	0.45	3	0.45	1
Deciduous Forest	141	1	7000	0.005	0.2	1.8	0.7	0.011	0.7	1
Evergreen Forest	142	1	7000	0.005	0.2	1.8	0.7	0.011	0.7	1
Mixed Forest	143	1	7000	0.003	0.2	1.8	0.75	0.011	0.75	1

Table A3
Land cover attribute table for pollinator abundance model

LULC	LULCname	LULC_GROUP	N_cavity	N_ground	F_spring	F_summer
131	Barren	Built	0.3	0.2	0.7	0.5
124	Developed/High Intensity	Built	0.3	0.2	0.7	0.5
122	Developed/Low Intensity	Built	0.3	0.2	0.7	0.5
123	Developed/Med Intensity	Built	0.3	0.2	0.7	0.5
6	Sunflower	Ag	0.1	0.7	0.5	0.3
44	Other Crops	Ag	0.1	0.7	0.5	0.3
121	Developed/Open Space	Built	0.3	0.2	0.7	0.5
43	Potatoes	Ag	0.1	0.7	0.5	0.3
46	Sweet Potatoes	Ag	0.1	0.7	0.5	0.3
61	Fallow/Idle Cropland	Ag	0.1	0.7	0.5	0.3
92	Aquaculture	Water	0	0	0	0
111	Open Water	Water	0	0	0	0
176	Grass/Pasture	Ag	0.1	0.7	0.5	0.3
1	Corn	Ag	0.1	0.7	0.5	0.3
2	Cotton	Ag	0.1	0.7	0.5	0.3
5	Soybeans	Ag	0.1	0.7	0.5	0.3
12	Sweet Corn	Ag	0.1	0.7	0.5	0.3
26	Dbl Crop WinWht/Soybeans	Ag	0.1	0.7	0.5	0.3
42	Dry Beans	Ag	0.1	0.7	0.5	0.3
53	Peas	Ag	0.1	0.7	0.5	0.3
57	Herbs	Ag	0.1	0.7	0.5	0.3
206	Carrots	Ag	0.1	0.7	0.5	0.3
222	Squash	Ag	0.1	0.7	0.5	0.3

Table A3 (*continued*)

LULC	LULCname	LULC_GROUP	N_cavity	N_ground	F_spring	F_summer
238	Dbl Crop WinWht/Cotton	Ag	0.1	0.7	0.5	0.3
3	Rice	Ag	0.1	0.7	0.5	0.3
4	Sorghum	Ag	0.1	0.7	0.5	0.3
24	Winter Wheat	Ag	0.1	0.7	0.5	0.3
27	Rye	Ag	0.1	0.7	0.5	0.3
28	Oats	Ag	0.1	0.7	0.5	0.3
36	Alfalfa	Ag	0.1	0.7	0.5	0.3
58	Clover/Wildflowers	Ag	0.1	0.7	0.5	0.3
152	Shrubland	Unkn	0	0	0	0
190	Woody Wetlands	Unkn	0	0	0	0
195	Herbaceous Wetlands	Ag	0.1	0.7	0.5	0.3
205	Triticale	Ag	0.1	0.7	0.5	0.3
10	Peanuts	Ag	0.1	0.7	0.5	0.3
48	Watermelons	Ag	0.1	0.7	0.5	0.3
70	Christmas Trees	Forest	0.4	0.3	0.3	0.3
74	Pecans	Ag	0.1	0.7	0.5	0.3
209	Cantaloupes	Ag	0.1	0.7	0.5	0.3
141	Deciduous Forest	Forest	0.4	0.3	0.3	0.3
142	Evergreen Forest	Forest	0.4	0.3	0.3	0.3
143	Mixed Forest	Harv	0.6	0.3	0.3	0.3

Table A4
Guild table for pollinator abundance model

SPECIES	NS_cavity	NS_ground	FS_spring	FS_summer	ALPHA	SPECIES_WEIGHT	CRP_a	CRP_c
Apis (Honeybee)	1	1	0.5	0.5	500	1	1	1
Bombus (Bumblebee)	1	0	0.4	0.6	1500	1	1	0

Table A5
Sensitivity of LULC classes to threats table for habitat quality model

LULC	NAME	HABITAT	L_Agr	L_Dev	L_Wll	L_Gre	L_Oil	L_Haz
131	Barren	0	0	0	0	0	0	0
124	Developed/High Intensity	0	0	0	0	0	0	0
122	Developed/Low Intensity	1	0.3	0.5	0.3	0.4	0.2	0.5
123	Developed/Med Intensity	0	0	0	0	0	0	0
6	Sunflower	1	0.3	0.5	0.3	0.3	0.5	0.7
44	Other Crops	1	0.3	0.5	0.3	0.3	0.5	0.7
121	Developed/Open Space	1	0.4	0.6	0.3	0.4	0.2	0.5
43	Potatoes	1	0.3	0.5	0.3	0.3	0.5	0.7
46	Sweet Potatoes	1	0.3	0.5	0.3	0.3	0.5	0.7
61	Fallow/Idle Cropland	1	0.3	0.5	0.3	0.3	0.5	0.3
92	Aquaculture	1	0.7	0.9	0.5	0.7	1	0.9
111	Open Water	1	0.7	0.9	0.5	0.7	1	0.9
176	Grass/Pasture	1	0.3	0.5	0.3	0.3	0.5	0.3
1	Corn	1	0.3	0.5	0.3	0.3	0.5	0.5

Table A5 (*continued*)

LULC	NAME	HABITAT	L_Agr	L_Dev	L_Wll	L_Gre	L_Oil	L_Haz
2	Cotton	1	0.3	0.5	0.3	0.3	0.5	0.5
5	Soybeans	1	0.3	0.5	0.3	0.3	0.5	0.5
12	Sweet Corn	1	0.3	0.5	0.3	0.3	0.5	0.5
26	Dbl Crop WinWht/Soybeans	1	0.3	0.5	0.3	0.3	0.5	0.5
42	Dry Beans	1	0.3	0.5	0.3	0.3	0.5	0.5
53	Peas	1	0.3	0.5	0.3	0.3	0.5	0.5
57	Herbs	1	0.3	0.5	0.3	0.3	0.5	0.5
206	Carrots	1	0.3	0.5	0.3	0.3	0.5	0.5
222	Squash	1	0.3	0.5	0.3	0.3	0.5	0.5
238	Dbl Crop WinWht/Cotton	1	0.3	0.5	0.3	0.3	0.5	0.5
3	Rice	1	0.3	0.5	0.3	0.3	0.5	0.5
4	Sorghum	1	0.3	0.5	0.3	0.3	0.5	0.5
24	Winter Wheat	1	0.3	0.5	0.3	0.3	0.5	0.5
27	Rye	1	0.3	0.5	0.3	0.3	0.5	0.5
28	Oats	1	0.3	0.5	0.3	0.3	0.5	0.5
36	Alfalfa	1	0.3	0.5	0.3	0.3	0.5	0.5
58	Clover/Wildflowers	1	0.3	0.5	0.3	0.3	0.5	0.5
152	Shrubland	1	0.4	0.6	0.3	0.4	0.2	0.5
190	Woody Wetlands	1	0.4	0.6	0.5	0.4	0.6	0.6
195	Herbaceous Wetlands	1	0.3	0.5	0.3	0.3	0.5	0.5
205	Triticale	1	0.3	0.5	0.3	0.3	0.5	0.5
10	Peanuts	1	0.3	0.5	0.3	0.3	0.5	0.5
48	Watermelons	1	0.3	0.5	0.3	0.3	0.5	0.5
70	Christmas Trees	1	0.5	0.7	0.3	0.5	0.2	0.2

Table A5 (*continued*)

LULC	NAME	HABITAT	L_Agr	L_Dev	L_Wll	L_Gre	L_Oil	L_Haz
74	Pecans	1	0.3	0.5	0.3	0.3	0.5	0.5
209	Cantaloupes	1	0.3	0.5	0.3	0.3	0.5	0.5
141	Deciduous Forest	1	0.5	0.7	0.3	0.5	0.2	0.2
142	Evergreen Forest	1	0.5	0.7	0.3	0.5	0.2	0.2
143	Mixed Forest	1	0.7	0.9	0.7	0.7	0.5	0.5

Table A6
Threat assessment table

MAX_DIST	WEIGHT	THREAT	DECAY
5	1	Agr	linear
5	1	Dev	exponential
5	0.75	Wll	linear
5	0.5	Gre	exponential
5	0.5	Oil	exponential
5	0.75	Haz	exponential

APPENDIX B

GCAD Agricultural Productivity Values

Classification	**Code**	**Value per acre**
Rice production	A1	$235.00
Rice/soybean pasture rotation	A2	110.00
Rice/pasture rotation	A3	135.00
Soybeans	B1	95.00
Other dry cropland	B2	75.00
Improved pasture and/or hay	D1	95.00
Native pasture/mostly clean	El	40.00
Native pasture/brushy, wooded	E2	30.00
Native pasture/low elevation, marshy	E3	20.00
Native pasture/low elevation, marshy Also used for hunting	E4	45.00
Native pasture/high island-low Elevation, marshy	E5	15.00
Native pasture/high island-low Elevation, also used for hunting	E6	40.00
Pecan orchards	C1	300.00
Floriculture	F1	300.00
Horticulture	F2	300.00
Truck farming	F3	300.00
Turf grass	F4	300.00
Bee production/honey	F5	95.00
Goat/sheep production	F6	95.00
Ratite production	F7	1,500.00
Wildlife management	F8	40.00
Fish farming	F9	5,050.00

APPENDIX C

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)
(1) Phosphorus export	1.00																														
(2) Nitrogen export	0.77	1.00																													
(3) Sediment Export	0.47	0.29	1.00																												
(4) Water yield	0.16	0.07	0.16	1.00																											
(5) Pollination abundance	-0.28	-0.17	-0.22	-0.15	1.00																										
(6) Pollination abundance in ag cell	-0.12	-0.03	-0.08	-0.03	0.44	1.00																									
(7) Habitat degradation	-0.31	-0.09	-0.28	-0.18	0.32	0.19	1.00																								
(8) Habitat quality	-0.16	-0.11	-0.13	-0.06	0.23	0.14	0.23	1.00																							
(9) Slope	0.20	0.35	0.23	-0.02	-0.19	-0.07	0.19	-0.14	1.00																						
(10) CPI	-0.43	-0.20	-0.46	-0.31	0.44	0.18	0.53	0.35	-0.11	1.00																					
(11) Parcel size	0.19	0.08	0.18	0.61	-0.22	0.05	-0.25	-0.09	-0.03	-0.38	1.00																				
(12) Distance to closet city	-0.17	-0.04	-0.17	-0.03	0.31	0.23	0.63	-0.05	0.14	0.22	-0.12	1.00																			
(13) Distance to major road	0.15	0.09	0.16	0.21	-0.11	0.12	-0.16	0.10	-0.05	-0.27	0.21	0.00	1.00																		
(14) Agricultural value/ha	-0.07	-0.03	-0.04	-0.04	0.08	-0.12	0.23	0.07	-0.02	0.16	-0.19	0.19	0.00	1.00																	
(15) Agricultural value * CPI	-0.15	-0.08	-0.13	-0.09	0.15	-0.11	0.29	0.12	-0.04	0.32	-0.24	0.21	-0.05	0.97	1.00																
(16) Improvement value	-0.03	-0.01	-0.05	-0.04	0.02	0.01	0.05	-0.04	0.02	0.05	-0.06	0.06	-0.03	0.01	0.02	1.00															
(17) Percent developed land	-0.15	-0.05	-0.24	-0.23	0.35	-0.35	0.22	-0.02	-0.01	0.31	-0.40	0.04	-0.43	0.12	0.18	0.07	1.00														
(18) Percent cultivate land	-0.17	-0.10	-0.12	0.06	0.03	0.34	0.21	0.19	-0.14	0.16	0.17	0.24	0.29	0.16	0.15	-0.04	-0.55	1.00													
(19) DICKINSON	0.08	0.06	0.05	-0.01	-0.17	-0.04	0.03	0.00	0.11	0.06	0.05	-0.03	-0.30	-0.09	-0.07	0.04	-0.07	-0.12	1.00												
(20) FRIENDSWOOD	-0.04	0.02	-0.03	-0.03	0.13	0.04	0.21	-0.03	0.14	0.05	0.00	0.17	-0.08	0.02	0.02	-0.01	0.12	-0.02	-0.07	1.00											
(21) GALVESTON	0.23	0.11	0.12	0.00	-0.23	-0.16	-0.33	-0.40	0.11	-0.46	0.10	0.00	-0.01	-0.09	-0.14	-0.03	-0.04	-0.16	-0.07	-0.02	1.00										
(22) HIGHISLAND	0.13	0.05	0.17	0.29	-0.14	-0.08	-0.26	-0.23	0.05	-0.31	0.21	0.21	0.09	-0.07	-0.09	-0.02	-0.10	-0.10	-0.05	-0.01	-0.02	1.00									
(23) HITCHCOCK	0.14	0.01	0.13	0.15	-0.17	-0.02	-0.46	-0.01	-0.11	-0.33	0.17	-0.56	0.28	-0.17	-0.21	-0.03	-0.22	0.03	-0.20	-0.06	-0.06	-0.04	1.00								
(24) LAMARQUE	0.02	0.02	0.05	-0.06	-0.12	-0.06	-0.17	0.00	0.00	0.06	-0.02	-0.38	-0.13	-0.12	-0.10	-0.04	0.00	-0.23	-0.13	-0.04	-0.04	-0.03	-0.12	1.00							
(25) SANTAFE	-0.26	-0.12	-0.23	-0.11	0.36	0.15	0.47	0.20	-0.11	0.35	-0.22	0.52	0.14	0.28	0.32	0.03	0.16	0.30	-0.48	-0.15	-0.16	-0.10	-0.43	-0.29	1.00						
(26) TEXASCITY	0.07	0.07	0.12	-0.01	-0.13	-0.10	-0.16	0.00	0.04	-0.14	0.03	-0.18	0.00	-0.01	-0.05	-0.01	0.05	-0.09	-0.04	-0.01	-0.01	-0.01	-0.04	-0.02	-0.09	1.00					
(27) Very poorly drained	0.04	0.02	0.26	0.02	-0.22	-0.13	-0.11	-0.07	0.10	-0.25	0.07	-0.13	0.06	-0.05	-0.08	-0.01	-0.07	-0.09	-0.01	-0.01	-0.01	-0.01	0.02	0.10	-0.09	0.24	1.00				
(28) Poorly drained	-0.08	-0.12	-0.06	-0.01	0.16	-0.04	-0.19	0.01	-0.19	0.09	-0.09	-0.15	0.05	-0.01	0.02	0.01	0.20	-0.06	-0.15	-0.09	-0.04	-0.06	0.19	-0.12	0.11	-0.01	-0.05	1.00			
(29) Somewhat poorly drained	-0.04	-0.02	0.00	-0.03	0.10	0.06	0.13	0.06	0.00	0.06	-0.06	0.07	-0.11	0.04	0.04	0.01	0.01	0.00	0.00	-0.01	-0.13	-0.07	0.00	-0.05	0.06	0.02	-0.07	-0.53	1.00		
(30) Not prime farmland	0.30	0.16	0.34	0.14	-0.24	-0.10	-0.39	-0.21	0.11	-0.61	0.23	-0.25	0.16	-0.14	-0.23	-0.04	-0.16	-0.18	-0.09	-0.06	0.28	0.18	0.36	0.02	-0.31	0.16	0.16	-0.18	0.17	1.00	
(31) Prime farmland if drained	-0.03	-0.02	-0.03	0.02	0.00	0.08	-0.11	0.02	-0.07	0.06	0.01	-0.08	0.05	-0.04	-0.03	0.00	-0.07	0.04	0.03	-0.05	-0.05	-0.04	0.19	-0.02	-0.14	-0.03	-0.03	0.38	-0.13	-0.19	1.00

APPENDIX D

Box-Cox functional form test for dependent and explanatory variables

Box-cox transformation (Box and Cox, 1964) was used to identify the most suitable functional form for dependent and explanatory variables. Results indicated that logarithmic transformation ($\lambda = 0$) was adopted.

Test H_0:	Restricted log likelihood	LR statistic χ~**chi2**	P-value Prob > chi2
theta=lambda = -1	-16019.487	4960.20	0.000
theta=lambda = 0	-13541.545	4.32	0.038
theta=lambda = 1	-16296.649	5514.52	0.000

APPENDIX E

Spatial autocorrelation tests were used to determine appropriate cut-off distance for spatial weights used in spatial error models (Table E1). Lagrange Multiplier tests were used to determine appropriate spatial autocorrelation model for the analysis (Table E2). Results indicated that a spatial error model was associated with spatial autocorrelation in the model and was used for further analysis.

Table E1
Multi-distance spatial cluster analysis in GIS indicates a distance of 2143.7598 as a suitable cut-off distance.

Distance	Moran's I	Variance	z_score	p_value
2143.7598	0.1541	0.0001	17.0290	0.0000
2434.1388	0.1433	0.0001	17.0008	0.0000
2724.5178	0.1202	0.0001	15.7936	0.0000
3014.8967	0.1024	0.0001	14.4672	0.0000
3305.2757	0.0888	0.0000	13.5767	0.0000
3595.6547	0.0859	0.0000	14.3001	0.0000
3886.0337	0.0928	0.0000	16.2762	0.0000
4176.4127	0.0907	0.0000	16.9529	0.0000
4466.7916	0.0801	0.0000	16.0045	0.0000
4757.1706	0.0717	0.0000	15.2751	0.0000

Table E2
Spatial diagnostics – Lagrange Multiplier tests

Test	df	Value	p-value
Lagrange Multiplier (lag)	1	183.263	0.000
Robust LM (lag)	1	7.357	0.067
Lagrange Multiplier (error)	1	335.417	0.000
Robust LM (error)	1	159.512	0.000
Lagrange Multiplier (SARMA)	2	342.775	0.000